

ANALYSIS OF SUDDEN NATURAL DEATHS WHILE DRIVING WITH FORENSIC AUTOPSY FINDINGS

Yasuki Motozawa

Honda R&D Co., Ltd./Department of Legal Medicine, Dokkyo University School of Medicine
Japan

Tomoko Yokoyama

Department of Oral and Maxillofacial Surgery, Dokkyo University School of Medicine
Japan

Masahito Hitosugi, Shogo Tokudome

Department of Legal Medicine, Dokkyo University School of Medicine
Japan

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ABSTRACT

Sudden natural death while driving has been insufficiently elucidated in Japan owing to the system of voluntary notification of relevant diseases when applying for driver's licenses and the low autopsy rates of traffic accident deaths. This report discusses the behaviors of the vehicles immediately after the drivers' death and the circumstances of the accidents with information obtained from police and the forensic autopsy findings. The results suggested that in a number of cases the cause of death of the driver might be misidentified as injuries resulting from an accident caused by human error such as delayed recognition, misjudgment or mishandling of the vehicle, if autopsy had not been performed. Furthermore, accidents caused by sudden natural death of the driver might be misclassified among fatal accidents in Japanese traffic statistics.

Our results demonstrate the importance of employing information gained from autopsy records in accident analysis to distinguish between fatal accidents and sudden natural death while driving, in order to clarify the degree to which human factors contribute to causing accidents.

INTRODUCTION

Dramatic improvements have been made in automotive collision safety performance in recent years as a result of continuous upgrades in global safety standards. In Japan, the results of assessments by the JNCAP, the country's first independent automotive safety evaluation body, have been made public since 1999, providing consumers with more detailed information on automotive collision safety. This has contributed to increased concern among Japanese consumers regarding safety performance, leading to a noticeable increase in the use of safety devices in automobiles. Although fatalities of vehicle occupants in automobile accidents have been decreased in Japan since 1995, they have still exceeded 3000 in 2003 [1].

Traditionally, the human factors accounting for road traffic accidents have mainly been classified as human error; i.e. delayed recognition, errors in judgment, mishandling of the vehicle. However, when we examined such accidents in detail, we found that some driver might have lost consciousness, or had already been dead before the accident, because the cause of death was diagnosed as sudden natural death with forensic autopsies. Given the likelihood that human error is not the cause of such accidents and those injuries sustained by the driver are not the direct cause of death, these accidents must clearly be distinguished from other fatal accidents. However, this fact has been underestimated in conventional studies. This paper will deal with sudden natural death of the while operating the vehicle. We analyze the subsequent behavior of the vehicle, the characteristics of the resulting accident, previous medical histories of the driver and autopsy findings. Furthermore, the paper will discuss Japan's legal regulations concerning competence in vehicle operation and the importance of forensic autopsy to distinguish between natural deaths while driving and traffic accident fatalities.

ACCIDENT STATUS

In Japanese traffic accident statistics, human factors accounting for traffic accidents are generally classified as human error, with a breakdown as follows (All percentages refer to single vehicle fatal accidents): Delayed recognition, due to forward inattention, etc. (27%), errors in judgment (27%), mishandling of the vehicle (40%) [2]. The majority of human error is ascribed to alcohol or fatigue; the statistical data does not refer to the effects of natural diseases in Japan. Although many studies of sudden natural death while driving have been reported to date [3]-[8], no comprehensive analysis concerning the circumstances of the accidents or avoidance maneuvers of the drivers of the vehicles involved have been shown. In addition, physical and mental

factors are not studied in Japanese national traffic accident surveys and have not been well recognized and appeared as a category in national statistics. Furthermore, most of surveys in specific regions have reported either the circumstances leading to accidents and the vehicles involved or medical findings concerning natural diseases suffered by the drivers. Therefore, it is urgently necessary to clarify the status of accidents due to sudden natural death and to obtain a comprehensive perspective on this issue for evaluating the risk of fatal accidents caused by natural diseases and for preventing them.

HEALTH PROBLEMS AND ROAD TRAFFIC LAW

Japan's Road Traffic Law was partially revised in 1999 with the formulation of new laws concerning conditions for the disqualification of disabled persons from holding drivers' licenses. These laws came into effect in June 2002. This revision of the Law did away with former provisions stating that individuals suffering from specific medical conditions were disqualified from holding a driver's license (or from taking a licensing test), and has provided, instead, for judgment in individual cases as to whether the driver's medical condition would affect their ability to drive safely.

In cases where an applicant for a license suffers from one of the conditions listed below and there is concern that the condition will diminish their ability to drive safely, the license may be refused or held back, even if the driver has successfully passed the test. (In the case of individuals already possessing a license, the license may be revoked or suspended). The specific conditions are involved in:

1. Schizophrenia
2. Epilepsy
3. Recurrent syncope
4. Asymptomatic hypoglycemia
5. Manic-depressive psychosis
6. Severe dyssomnia
7. Other conditions involving symptoms which may diminish the ability to drive an automobile safely

Where a driver has declared that they have any of the conditions listed above or the symptoms listed below, the Public Safety Commission has the power to conduct individual interviews and, where necessary, to hold back or suspend licenses. At this time the driver may be requested to submit a medical certificate, and tests may be conducted. The symptoms are:

1. The driver has lost consciousness due to illness or an undetermined cause.
2. The driver has experienced paroxysmic general or local seizures or paralysis as a result of illness.
3. The driver falls asleep in the midst of their daily activities three or more times a week, despite getting sufficient sleep.
4. The driver has been advised by a physician not to obtain a driver's license or drive a vehicle due to illness.

Declaration of these conditions or symptoms which may disqualify the driver from holding a driver's license is made on a special form when receiving or renewing a license. This system basically relies on self-declaration. In addition, making an accurate judgment on whether the driver has a possibility to lose consciousness while driving or not, is difficult. However, the law was revised as mentioned above in order to take the right of the disabled to drive into account. Evaluating the risk of fatal accidents due to natural diseases is therefore important in enabling discussion on standards to be established with regard to medical conditions which may result in loss of consciousness while driving. To do so, we must first clarify the status of accidents involving sudden natural death.

ANALYSIS OF SUDDEN NATURAL DEATH WHILE DRIVING WITH FORENSIC AUTOPSIES

In the seven-year period between 1997 and 2003, 130 forensic autopsies (an average of 18.6 per year) on fatalities in traffic accidents occurring in Tochigi Prefecture (in the north of the Kanto Region in which Tokyo is also located) were performed at the Department of Legal Medicine at the Dokkyo University School of Medicine. This represents almost all of the traffic accident-related forensic autopsies conducted in the prefecture during this period. In the traffic accident death, the cause of death is confirmed with the findings of clinical diagnosis and examinations. However, for the cases in which the clinical diagnosis is not defined; the death from suspicious accident; unknown death whether due to internal or external cause, forensic autopsy is performed. Because there were 1446 traffic accident fatalities in Tochigi Prefecture in the same period (an average of 206.7 per year) According to the statistics of Transportation Bureau of National Police Agency, the 130 autopsies conducted in the prefecture represent 9% of this figure. Cause of death was given as sudden natural death in 22 of these 130 cases. Even taking into consideration the fact that forensic autopsies are

generally only conducted when the cause of death is not easily determinable, this indicates that we may infer that accidents involving sudden natural death occur more often than we normally think.

Looking at a breakdown of the deaths from disease, we found that the average age at death was 55.6 ± 12.0 years, with males comprising 86% (19 cases). The leading cause of death is ischemic heart disease (73%, 16 cases). (Figure 1)

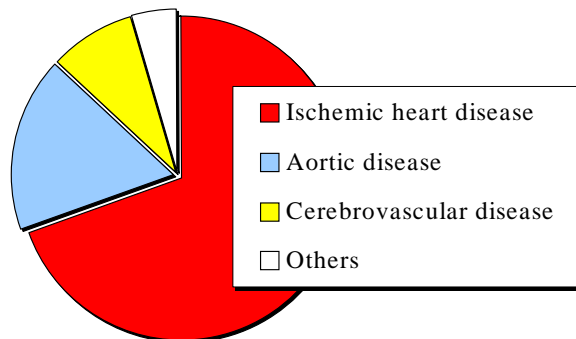


Figure 1. Distribution of Cause of Sudden Natural Death

In the following sections we discuss two autopsy cases with consideration of their implications.

Autopsy case 1

Accident circumstances

At approximately 8:00 in the morning, a 47-year-old woman wearing a seatbelt had been driving on a city street in a small passenger vehicle being equipped with no air bags. The vehicle made repeated contact with fences and walls on the left side of the street, coming to a stop after colliding with a utility pole on the right side of the street. Although the driver was transported to a hospital, she was pronounced dead at 1:30 in the afternoon.

Vehicle behavior during the accident

While traveling along an almost straight road of 5.4m in width, the vehicle struck a concrete block wall on the left side of the road. The vehicle proceeded approximately 20m and struck another wall on the left side of the road. Proceeding a further 13m, the vehicle again struck a stone wall on the left side of the road. The vehicle then proceeded approximately 120m and struck a utility pole on the left side of the road, after which it veered to the right, finally colliding almost head-on with a utility pole approximately 25m further on the right side of the road (Figure 2).

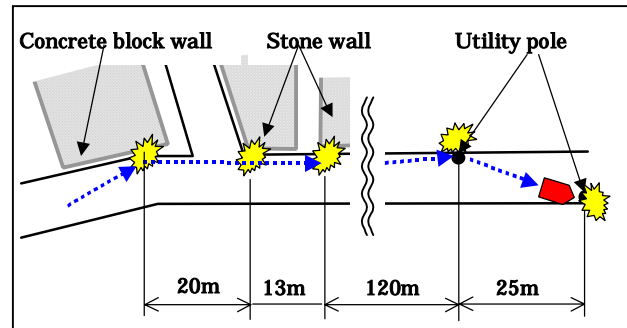


Figure 2. Vehicle Behavior of Case 1

Status of damage sustained by the vehicle

Frontal impact with the pole caused significant deformation of the front central section of the engine housing. (Figure 3) The steering wheel and column were deformed, but no significant deformation of the sides of the vehicle or of the cabin was observed.



Figure 3. Status of the Vehicle of Case 1

Autopsy findings

Height: 154.5cm; Weight: 46.5kg; Previous medical history: None.

Region of the head: Subarachnoid hemorrhage due to the rupture of aneurysm, a diameter of 1.5cm, at the top of the basilar artery was found, accompanied by a subarachnoid hemorrhage. No other traumatic changes were observed. (Figure 4)

Region of the neck: Hemorrhages in the soft tissue of the anterior surface of the cervical vertebrae and fractures of the 3rd intravertebral disk, and the 6th vertebral body of the neck, were observed. No abnormal findings in the dura of the cervical vertebrae and the spinal cord were found.

Region of the chest: Hemorrhage of the anterior surface of the pericardial cavity of the anterior mediastinum, and fractures of the right 8th rib (lateral part of the chest), right 9th-12th ribs (posterior part of the chest) and left 2nd rib (anterior part of the chest), and peripheral intramuscular hemorrhage were observed. No abnormal findings were found in the lungs, the heart and the thoracic aorta.

The cause of death was diagnosed as subarachnoid hemorrhage due to a ruptured aneurysm of the basilar artery.

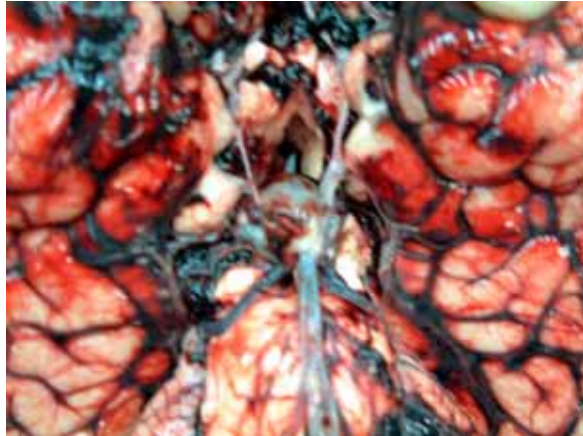


Figure 4. Subarachnoid hemorrhage shown in autopsy case 1

Considerations

In this case, during the accident the vehicle made repeated contact with structures at the side of the road, from the initial contact with a concrete block wall to the impact with the utility pole. There was no sign that the driver had attempted avoidance maneuvers by braking, turning the steering wheel, etc. during the accident. In addition, the scratches left by the initial contact with the wall suggest that it was a minor one, and given that she was wearing a seatbelt, it is difficult to imagine that it would have caused sufficient trauma to the driver to render her incapable of operating the vehicle. We may therefore infer that the driver was already incapable of steering the vehicle at the time of initial contact with the wall.

Although the trauma was caused by the secondary impact with interior components of the vehicle, none of which could have been the direct cause of death. Because of the presence of a ruptured aneurysm, the subarachnoid hemorrhage was judged to be endogenous, and the driver was judged to have died of natural causes. However, no prior medical history for the driver existed and multiple fractures were observed in the regions of the neck and chest, if no eyewitness accounts of the accident had been available, without autopsy, this accident would have

been incorrectly classified as mishandling of the vehicle.

Autopsy case 2

Accident circumstances

At approximately 7:45 in the morning, a 59-year-old man was driving on the expressway in a passenger vehicle. After making repeated contact with the guardrails on the left and right sides of the road, the vehicle collided with a guardrail on the median divider and came to a stop. The police arrived at the scene at 7:57 and found the driver unconscious. He was wearing a seatbelt and the airbag was inflated. An ambulance arrived at 8:06, at which time the driver was judged to be in a state of cardiopulmonary arrest. Although he was transported to a hospital, where he was pronounced dead at 8:50.

Vehicle behavior during the accident

At an estimated speed of 100km/h, the vehicle struck a guardrail on the median strip at a gentle right-hand curve, and continued in contact with the rail for several meters. The vehicle then veered to the left and proceeded for approximately 100m. It struck a guardrail on the left shoulder of the expressway and continued for approximately 30m in contact with it. The vehicle then veered to the right and proceeded for approximately 80m. It struck a guardrail on the median strip and continued in contact with the rail for approximately 70m, when it came to rest with its right side in contact with the rail. Slip marks were observed in the gutters at the points where the vehicle struck the guardrails, but there were no skid marks on the road surface, indicating that the driver had applied the brakes. (Figure 5)

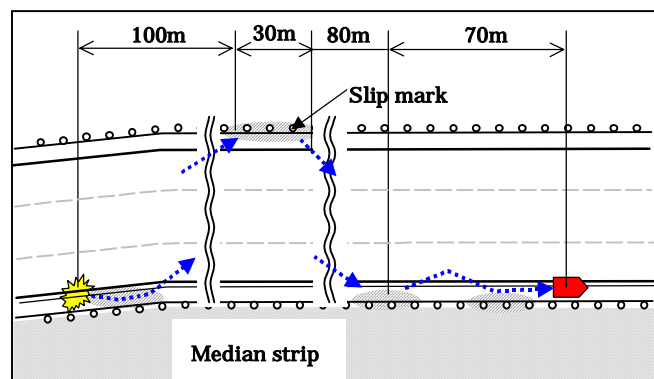


Figure 5. Vehicle Behavior of Case 2

Status of damage sustained by the front suspension and wheel were broken. No significant damage to the engine housing or deformation of the

cabin was observed. Both front airbags were inflated. (Figure 6)



Figure 6. Status of the Vehicle of Case 2 Just after the Crash

Autopsy findings

Height: 166cm; Weight: 64kg; Previous medical history: Angina pectoris. No traumatic changes were observed on the body surface.

Internally arterosclerosis and stenosis of the coronary arteries were observed. No other abnormal regions were found except the findings of acute death. Histologically massive ischemic changes of the cardiac muscle were found. The cause of death was diagnosed as ischemic heart failure (natural causes).

Considerations

Viewing this case from the perspective of vehicle behavior (the fact that there was no evidence of avoidance maneuvers, etc.), we may infer that the driver was already unconscious or dead when the vehicle first struck the guard rail on the center divider. Slip marks and the damage on the guard rails indicate that the airbag was probably triggered by the initial contact with the guard rail. However, because the vehicle remained virtually parallel to all the guardrails it scraped along, there was minimal impact to the vehicle or occupant. Furthermore, because the driver was wearing a seatbelt no trauma was observed. There was therefore little chance that this could be judged as a case of death due to accident trauma. However, if the vehicle had collided head-on with a man-made structure such as the pillar of a guardrail and the driver had consequently been injured, that the accident could be misjudged as a case of a driver having fallen asleep at the wheel.

CONCLUSION

Accidents occurring due to the sudden natural death of the driver are not caused by negligence in vehicle operation, and the injuries sustained by the driver in the accident are not the direct cause of death. Therefore, when accident surveys are conducted and when measures to prevent accidents are examined, this type of accident must be clearly distinguished from accidents due to human error such as mishandling of the vehicle. Therefore, we must first clarify status and attain a comprehensive understanding of these accidents.

In Japan, because forensic autopsies are conducted on only 4-5% of all traffic accident fatalities, in some cases the causes of deaths are not necessarily be accurately identified. In addition, there have traditionally been very few accident surveys and a lack of statistical data which deal with the sudden natural death of vehicle drivers. For this reason our knowledge of sudden death while driving is limited. Therefore, we must carefully determine whether the cause of death due to a natural disease or not, especially in a condition which might cause loss of consciousness or sudden death. With considering the past medical histories of the driver, we must actively carry out autopsies to determine the cause of death. At the same time, it is essential that we record the details of these accidents and thus accumulate knowledge. To enable this, in future it will be necessary, in addition to expanding the scope of accident surveys, to share knowledge with medical staff and relevant government agencies, and to create a system ensuring that these accidents are not overlooked. Autopsy results will play an important role in this process.

Moreover, we must also put into effect preventative safety measures, which take into consideration the physical condition of drivers, in order to reduce the incidence of these types of accidents, and also implement measures to prevent secondary accidents which may result from them.

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NEW TOOLS TO REDUCE DEATHS AND DISABILITIES BY IMPROVING EMERGENCY CARE: *URGENCY* SOFTWARE, OCCULT INJURY WARNINGS, AND AIR MEDICAL SERVICES DATABASE

Howard R. Champion, Research Professor of Surgery, Uniformed Services University of the Health Sciences, Principal Investigator,

Augenstein JS, Professor of Surgery, University of Miami; **Blatt AJ**, Senior Scientist, General Dynamics; **Cushing B**, Surgeon, Maine Medical Center; **Digges KH**, Professor of Engineering, George Washington University; **Flanigan MC**, Physical Scientist, General Dynamics; **Hunt RC**, Emergency Physician, CDC; **Lombardo LV**, Physical Scientist, NHTSA; **Siegel JH**, Professor of Surgery, University of Medicine and Dentistry of New Jersey. United States

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ABSTRACT

Research by the U.S. Department of Transportation, Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA) has developed technologies to improve transport and treatment of crash victims. Multidisciplinary (engineering, medical, and epidemiological) research has been initiated to improve the ability for: (a) identifying the approximately 250,000 crashed vehicles with occupants that probably have serious injuries each year, (b) alerting emergency medical care providers to the potential for serious (especially occult) injuries, and (c) enhancing the timeliness and quality of rescue and treatment through better utilization of air medical services. These improvements will lead to reducing the deaths and disabilities resulting from crash injuries.

This paper describes recent advances in tools to improve the rescue, transport, and treatment of seriously injured crash victims. Specifically, this paper reports on the development of *URGENCY* software for crash injury assessment, an Occult Injury Database (OID) for emergency medical warning flags, and the Atlas & Database of Air Medical Services (ADAMS). These tools provide for timely and appropriate rescue actions when needed.

Introduction - NHTSA Administrator Dr. Jeffrey W. Runge recently described the current motor vehicle crash problem and available safety advances as follows: *"Serious crashes happen every day, more than half of them in rural areas where the ability to rapidly contact 9-1-1 and the capability of responders to quickly reach the scene can mean the difference between life and death. New technologies such as wireless E9-1-1, automatic collision*

notification and emergency vehicle route navigation are available that will make emergency access more reliable and help deliver faster and better care." [1]

This paper describes recent research and development activities that support the delivery of faster and better care.

Background -- In September 1966, the National Academy of Sciences (NAS) issued a report that found *"49,000 deaths in 1965 were due to motor-vehicle accidents."* That report, *Accidental Death and Disability: The Neglected Disease of Modern Society*, focused on emergency care noting that *"Data are lacking on which to determine the number of individuals whose lives are lost or injuries are compounded by misguided attempts at rescue or first aid."* [2] The title, the findings, and many of the recommendations in that 1966 report are applicable to this day 39 years, and more than 1,750,000 crash deaths and 10 million serious crash injuries, later in the U.S. [3-6].

The NAS report also pointed to the need for research to improve diagnosis and treatment of injuries, stating that *"findings are important to alert emergency department staffs to the incidence of covert injuries that might well dictate first priority care, as well as the care and prophylactic measures that must be observed during definitive care and rehabilitation."*

Dr. William Haddon, the first Administrator of NHTSA, directed NHTSA to perform research to improve the emergency treatment of crash victims. An early study funded by the agency, published in 1971, *"Alcohol and Highway Safety: Behavioral and Medical Aspects"* highlighted the need for improving emergency medical treatment of crash injuries, including early recognition of internal (covert, occult, or hidden) injuries. [7]

In 1973, Dr. Haddon wrote *"The ninth strategy in loss reduction is to move rapidly in detection and evaluation of damage that has occurred. The generation of a signal that response is required; the signal's transfer, receipt, and evaluation; the decision to follow-through, are all elements here—whether the issue is wounds on the battlefield or highway."* [8]

Methods - Members of the research team were brought together by NHTSA for their expertise in trauma care research, advanced technologies, emergency medicine, crash data analysis, and motor vehicle crashworthiness engineering. The team, in

recent years, performed a series of statistical analyses of data on crashes, deaths, and injuries [11-18, 44]. The sources of the data included the Fatal Analysis Reporting System (FARS), the National Automotive Sampling System (NASS), and the Crash Injury Research and Engineering Network (CIREN).

Some of the multidisciplinary team members came from the NHTSA CIREN Centers. CIREN researchers study the most serious crash injuries – those that result in deaths, disabilities and loss of livelihoods. These injuries represent about 12 percent of all crash injuries, but account for about 77 percent of the economic costs of crash injuries. The costs associated with serious crash injuries amount to about \$112 billion in economic costs (excluding value for pain and suffering) each year. [1]

Over the past ten years research and development was conducted to refine the analyses and develop tools that could be used to improve triage, transport, and treatment decision-making for future crash victims. The team has presented its findings and recommendations at various stages to the NHTSA and to other organizations concerned with reducing morbidity and mortality of crash victims. This paper provides further updates on these efforts. [11-18].

The Problem –Each year, along the 4 million miles of roads in the U.S., about 5 million Americans are injured in 17 million crashes involving 28 million vehicles. Among those 28 million crash-involved vehicles, approximately 250,000 Americans suffer seriously life-threatening Abbreviated Injury Scale (AIS 3+) injuries. Specifically where and when they will occur is not predictable. Thus, it is important to be able to rapidly distinguish the one crashed vehicle that has a seriously injured person from the 100 crashed vehicles that have no injury or simply minor injuries.

Historically, each year a growing number and percentage of all crash deaths were Not Taken to a medical facility for treatment. And many people currently Taken to a medical facility for treatment die from crash injuries without the benefit of timely definitive care.

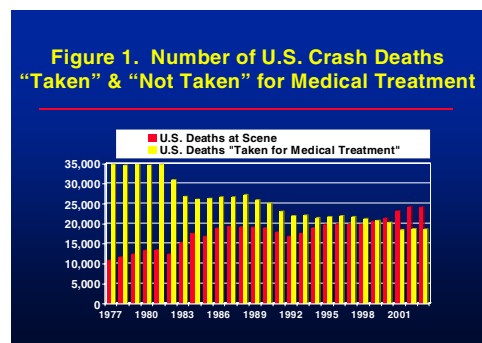


Figure 1 shows that in the year 2002, the number of people dying in crashes without being taken to a medical treatment facility amounted to 23,795 deaths, nearly 56 percent of crash deaths. The percentage of crash fatalities each year that are Not Taken to a medical treatment facility has increased over the past 15 years. The number of crash fatalities Taken for medical treatment has declined to 18,463, and this percentage has declined to 43 percent, in 2002. [18]

Both the fatalities Taken and those Not Taken suffered serious injuries. But limitations of FARS data on injury severity do not permit distinguishing survivable from non-survivable injuries. Thus, the number of these people that might have survived with timely, definitive medical care is unknown. While the number that might have survived is currently unknown, the research reported herein indicates that with new technologies, substantial benefits may be possible. Other researchers have estimated potential benefits ranging from hundreds to thousands of lives saved each year with improvements in post-crash care. [24, 30-32, 45]

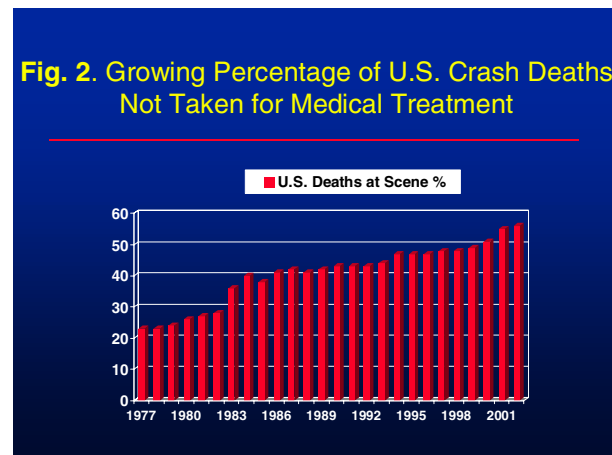


Figure 2 shows that in the year 2002, the percentage of people dying in crashes without being taken to a medical treatment facility amounted to nearly 56 percent of crash deaths. The percentage of crash fatalities each year that are Not Taken to a medical treatment facility has increased steadily over the years. The percentage of crash fatalities Taken for medical treatment, conversely, has steadily declined.

The increase in the number and percent of deaths at the scene may be due to a number of factors. More research is needed to understand the cause(s) of the increase in the number and percentage of "dead at the scene" and the possible remedies.

Reducing Time from Crash to Trauma Center --

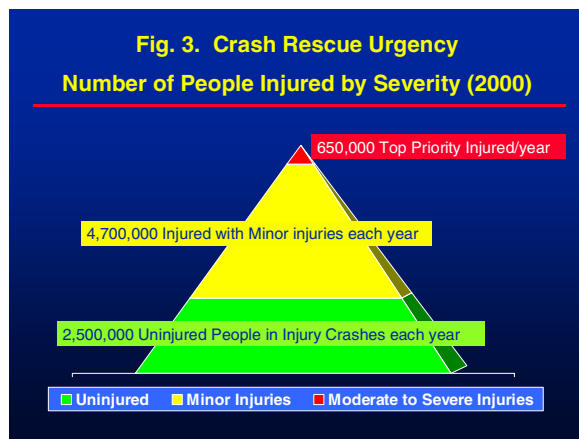


Figure 3 categorizes crash injuries in terms of their severity and urgency of treatment in all crashes involving injuries. The most important (life, or livelihood, threatening) injuries need to be treated differently from the more numerous cases of minor and uninjured people in crashes. Those with serious injuries require advanced emergency care while those with minor or no injury do not. The challenge is to distinguish and treat appropriately and rapidly the urgent injuries from the minor injuries.

In Figure 3, the top category shows that about 650,000 people suffer moderate to severe threat-to-life (AIS 2+), high priority, injuries each year. Currently some, but an unknown portion, of these people are under-triaged, i.e., receive less than optimal care in terms of timeliness, quality, and/or place of treatment (e.g., seriously injured not taken directly to a trauma center). Under-triage can result in needless deaths and disabilities.

The lower two categories show that there are about 7 million people who suffer minor or no injuries in crashes each year. Currently some, but an unknown portion, of these people are over-triaged to hospitals and trauma centers and found not to need the highest level of medical treatment. Over-triage can result in needless added health care costs.

Thus, tools are needed to better allocate emergency medical resources according to need, both for providing life saving care to those who need it, and for economic savings for those without serious injuries.

Note that the injury severity level often is not known at the time and scene of the crash. Thus, it is important to develop information systems and protocols that help to distinguish those who are likely to have serious injuries from those who are unlikely to have serious injuries – and to do so both faster and more accurately than we do today.

Since 1977, more than 1 million people have died from crash injuries along U.S. roads. Nearly 500,000

of these people died from crash injuries without having been taken to a medical treatment facility. Each year 43,000 people die and 650,000 suffer disabling injuries. Many of these people could benefit from faster, more informed, transport and treatment [4].

The morbidity of serious injuries is described by the trauma maxim “Time is tissue.” As an injury results in bleeding or edema, the longer tissue is deprived of oxygen and normal function, the greater the deterioration. And the longer the deterioration is allowed to progress, the greater the complexity of treatment, and the greater the long-term consequences. Long-term consequences include decreased physical function, pain, suffering, psychological and sociological problems, and economic harm.

Timely, optimal treatment is necessary to reduce morbidity resulting from many crash injuries occurring each year. Nearly 66,000 serious brain injuries occur to light vehicle occupants each year. About 3,500 serious spinal cord injuries occur each year that often result in life-long disabilities including quadriplegia and paraplegia. Nearly 140,000 lower limb injuries (hip, leg, knee, ankle and foot) of moderate to serious threat to life are sustained in crashes each year. Another 20,000 upper limb injuries occur each year. [10] Many injuries involve critical joints that result in long-term disabilities, psychological and sociological problems, economic harm, and pain and suffering – especially when timely, optimal care is not received.

The literature of emergency medical care has long documented that for many serious injuries, time is critical. In a description by R Adams Cowley of the origin of the Maryland Shock Trauma Center (now a base for research by the Maryland CIREN team) completed in 1969:

“During these years of initial organization, it was learned that the first 60 minutes, “the golden hour,” after a life-threatening injury incident dictates whether a patient will live or die. Another factor influencing survival is access to an emergency medical system providing on-site resuscitation, evaluation, triage, and communication and transportation with care en route to a definitive care facility.” [60]

As described by RD Stewart:

“Trauma is a time-dependent disease. ‘The Golden Hour’ of trauma care is a concept that emphasizes this time dependency. That is in polytrauma (typically, serious crash victims suffer multiple injuries) patients, the first hour of

care is crucial, and the patient must come under restorative care during that first hour.... Pre-hospital immediate care seeks to apply supportive measures, and it must do so quickly, within what has been called the 'Golden Ten Minutes.'" [34]

Dr. John R. Border described the problems of polytrauma in a classic textbook "Blunt Multiple Trauma":

"Major errors in care are made when the principles that appear largely valid for a single injury are extrapolated to the blunt multiple trauma patient." [47, 57, 61-62]

Both the internal (difficult to detect) nature and extent of blunt trauma, and the compounding effects of multiple injuries combine to complicate the emergency medical treatment of crash victims. This need for rapid diagnoses and treatments for the optimal care of crash injuries makes them time critical.

The authors of this paper compared the available data on fatal crashes in FARS with the goal of trauma care to get seriously injured patients into a trauma center for diagnosis, critical care and appropriate surgical treatment within the "Golden Hour" [14, 17, 18]. The team used the time benchmarks in Fig. 4 for data available in FARS on the delivery of patients to medical facility care within the "Golden Hour." [9]

[Note that the FARS currently does not contain data on the capability level of medical facilities to which victims in fatal crashes have been transported for treatment, nor does FARS currently contain data on methods of transport (air, ground, or ground and air)].

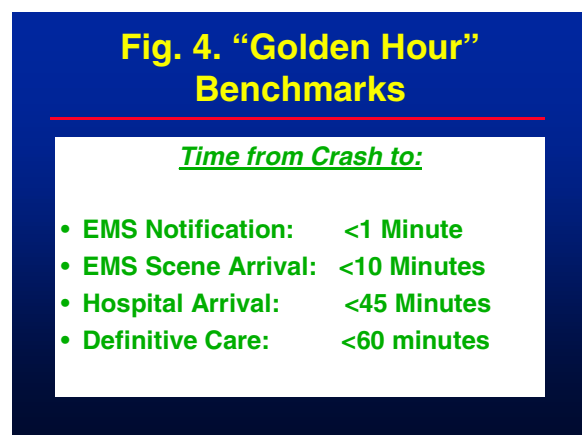


Figure 4 shows the medical benchmarks of the "Golden Hour" to provide optimal care for seriously injured crash victims.

Fig. 5. Fatalities in Crashes Meeting Benchmarks 2002

<u>Times</u>	<u>Benchmarks</u>	<u>Reported*</u>
EMS Notification	<1 minute	9,013 (21%)
Scene Arrival	<10 minutes	11,279 (26%)
Hospital Arrival	<45 minutes	6,004 (14%) (Taken + Not Taken)

* Only in Crashes with Reported Times

Figure 5 shows the number of fatalities in FARS 2002 that reportedly met medical benchmarks of the "Golden Hour" to provide optimal care for seriously injured crash victims.

Fig. 6. Average 2002 Performance Recorded in U.S. Rural Fatal Crashes

<u>Times</u>	<u>Benchmarks</u>	<u>Average*</u>
EMS Notification	<1 minute	7 minutes
Scene Arrival	<10 minutes	18 minutes
Hospital Arrival	<45 minutes	53 minutes
Definitive Care	<60 minutes	68 minutes

* Average Times for Crashes with Times <=120 minutes

Figure 6 shows the EMS average time performance in U.S. rural fatal crashes as recorded in FARS 2002. Note, only crashes with times less than 120 minutes were used to calculate average times to minimize effects of questionable and very long times on the averages. Average times to trauma center greater than 120 minutes have just been documented in the State of Maine. [66] Average EMS Notification times have declined nationally with the growing availability of cell phones over the past decade from 9 minutes to 7 minutes in fatal rural crashes [5].

Fig. 7 Needed Reductions in Average Times in Recorded U.S. Rural Fatal Crashes 2002

<u>Times</u>	<u>Benchmarks</u>	<u>Needed</u>
EMS Notification	<1 minute	- 6 minutes
Scene Arrival	<10 minutes	- 8 minutes
Hospital Arrival	<45 minutes	- 8 minutes
Definitive Care	<60 minutes	- 8 minutes

Figure 7 shows the needed reductions in *average* times in U.S. rural crashes. Methods by which these reductions can be achieved are indicated in Figure 8.

Fig. 8 Feasibility of Reductions in Average Times in Recorded U.S. Rural Fatal Crashes 2002

<u>Times</u>	<u>Reductions Needed</u>	<u>Feasible with</u>
EMS Notification	- 6 minutes	ACN
Scene Arrival	- 8 minutes	ACN + URGENCY
Hospital Arrival	- 8 minutes	Air Medical Services
Definitive Care	- 8 minutes	Trauma Systems (AACN+URGENCY+Air Med)

Figure 8 shows technologies that could be employed to reduce average times: Automatic Crash Notification (ACN) equipment, *URGENCY* software, Air Medical Services, and Trauma systems linked together via wireless communications systems. [23, 50-52]

The Need for Timely Intervention – In FARS 2002, there were 42,815 fatalities along U.S. roads; 23,795 fatalities (56%) were Not Taken for Medical Treatment and the rest died later.

Fig. 9 Percent Fatalities: Taken vs. Not Taken by Time Between Crash and EMS Notification (All Roads 2002)

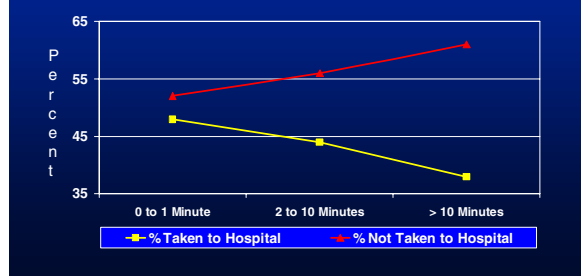


Figure 9 using FARS 2002 data, shows that the percent of fatalities Not Taken for medical treatment increases as the time between crash and EMS Notification increases while the percent Taken for medical treatment declines.

Fig. 10 Fatalities in 2002 by Times Between Crash & EMS Notification (0-120 Min)

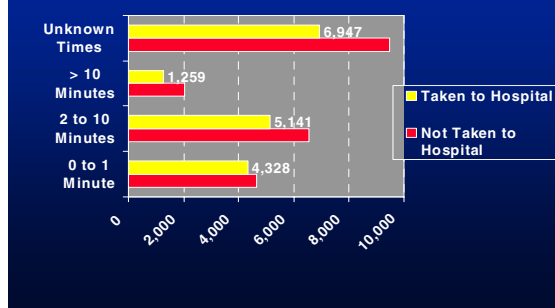


Figure 10 shows the numbers of fatalities in each time interval are not based on small numbers of cases. The percentages Taken versus Not Taken in Figure 9 are based on substantial numbers of cases in each time interval.

Fig. 11 Percent Fatalities: Taken vs. Not Taken by Times (0-120 Min) Between Crash and EMS Arrival at Scene (All Roads FARS 2002)

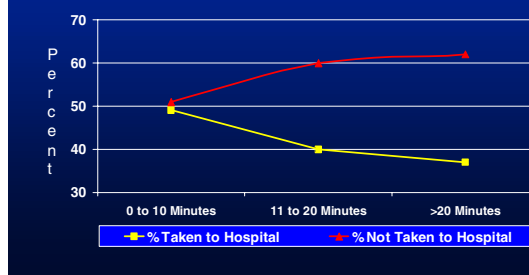


Figure 11 shows that the percent of fatalities Not Taken for medical treatment increases as the time between crash and EMS Arrival increases, while the percent Taken for treatment declines.

Fig. 12 Fatalities by Times Between Crash & EMS Arrival at Scene (2002)

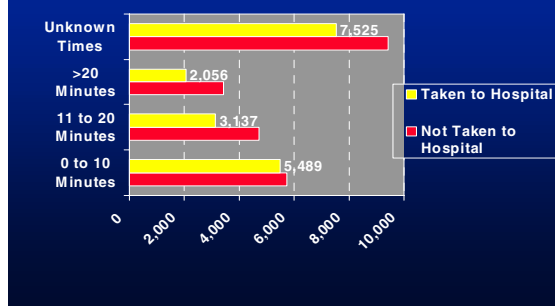


Figure 12 shows the numbers of fatalities in each time interval and indicates that the percentages Taken versus Not Taken in Figure 11 are based on

substantial numbers of cases in each time interval. The later the arrival, the greater the percentage of people Not Taken for treatment in that time interval. These data support the “Golden Ten Minutes” rule.

Finding Serious Injury Crashes – Run-off-the-road (ROR) crashes are an important safety problem resulting in 17,927 fatalities in the year 2002. Vehicles that run off the road and crash may be difficult to see. In ROR crashes in 2002, there were 11,068 fatalities that were Not Taken for medical treatment and 6,686 fatalities that were “Taken.” [9]

Decreased visibility also is often present complicating location of the crash. Decreased visibility is defined as times between dusk and dawn and/or weather conditions involving snow, rain, and/or fog. In 2002, of the 17,927 fatalities in ROR crashes there were 11,120 fatalities with decreased visibility conditions and 6,807 fatalities without decreased visibility. [9]

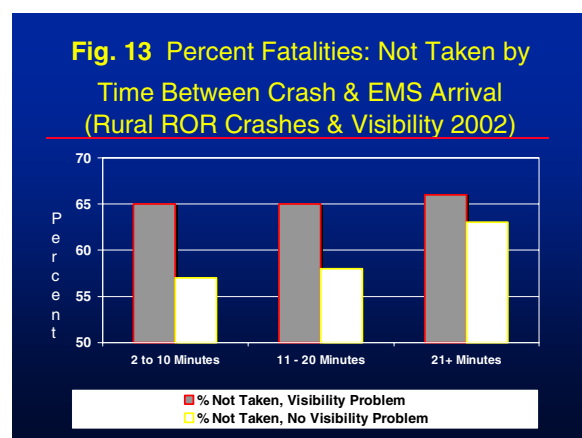


Figure 13 shows that in rural run-off-the-road crashes, with decreased visibility, the percent of fatalities Not Taken for medical treatment is greater in each time interval when visibility is impaired.

In many such crashes, ACN technologies can help locate the crash and speed the delivery of emergency services because accurate GPS locations are provided even if the crashed vehicle is out of sight from the road or not easily seen because of poor visibility conditions.

Urban/Rural -- A recent report published by NHTSA described the problem of preventable mortality in rural areas as follows: “Typically, rural areas have a higher preventable mortality rate than urban regions. This may be due to a number of factors, such as the time elapsed from the emergency call to the arrival of the ambulance at the scene of the incident, the time for the ambulance to reach the trauma center, insufficient experience with certain trauma procedures due to infrequent occurrences,

and inadequate training for EMS personnel in rural areas.” [39]

Using Crash Scene Information to Improve Care –

Meeting the Safety Need with Information

Technology: URGENCY Software - To advance, in Dr. Haddon’s words, “the detection and evaluation of damage....and the generation of a signal that response is required”, the research team has developed the nation’s first prototype software called *URGENCY* and worked on subsequent versions. This tool is designed to help detect and evaluate crashes to distinguish serious injury crashes from non-serious injury crashes. A research version of the latest *URGENCY* software prepared by Drs. Bahouth and Digges is available for academic review at:

<http://surgery.med.miami.edu/williamlehman/>

Research on *URGENCY* software continues through development of two software packages *SCENE URGENCY* software and Automatic Crash Notification (ACN) *URGENCY* software. [16] *SCENE URGENCY* addresses current needs of responders to crashes to better assess the probability of serious injury presence. *ACN URGENCY* addresses the future need to assess injury probabilities in crashes of new vehicles equipped with ACN systems. The goal is to save crash victims from death and disability through the application of engineering knowledge of crash injury mechanisms and probabilities of serious injuries.

Future research also is expected to help us better estimate the potential benefits in mortality and morbidity reductions possible with faster and better emergency medical decision-making. Hopefully, in the future, improvements in triage, transport, and treatment, with ACN, *URGENCY*, and earlier and better utilization of Air Medical Services will reduce the number of deaths of people -- both those “Taken for Treatment” and those “Not Taken for Treatment.”

ACN with *URGENCY* information on crash severity can help dispatchers, instantly and automatically, decide to send appropriate resources such as extrication equipment in severe crashes, thereby, saving additional precious minutes.

Extrication -- Extrication is an increasingly important factor in fatal crashes [17]. In 1990, extrication was involved in crashes resulting in 4,426 fatalities. In 2002, nearly 10,000 fatalities occurred in crashes involving extrication. [9] Extrication requires specialized equipment and trained rescue teams to remove occupants rapidly and safely. First responders to the scene may have to wait for heavy rescue teams to extricate the crash victim.

Once heavy rescue teams arrive at the scene of serious injury crashes, extrication can take many precious minutes. CIREN researchers have found that in serious injury crashes extrication often takes more than 20 minutes. [65] The NHTSA/CIREN database, as of Nov. 2004, has 123 cases with extrication times equal to or less than 20 minutes and 102 cases of extrication times equal to or greater than 21 minutes.

In future implementations, ACN and *URGENCY* information could save valuable time by alerting dispatchers that the crash severity information, e.g., rollover, near side impact, high Delta V, indicates heavy rescue teams might well be needed. In addition, since the ACN crash message includes the make and model of the crashed car, it is now technically possible for heavy rescue teams to receive extrication information on the number of air bags, their location, and vehicle cut points specifically for the crashed vehicle – before arriving at the scene.

Alternatively, for all vehicles currently on the road, crash evaluation services could be provided by a third party, either via call center, wireless internet, or software carried by rescue personnel on PDA's or laptop computers. Such systems could provide rescue teams with extrication information specifically for the crashed vehicle using the Vehicle Identification Number (VIN) – shortly after arriving at the crash scene.

More advanced versions of *URGENCY* software will employ additional sensor data to create a more robust and sophisticated triage, transport, and treatment decision-making tool. Future *URGENCY* ratings may calculate the probabilities of the presence of minor as well as major injuries. Information will be included such as the number, size, and seating positions of occupants, seat track location (closeness to air bag), crash pulse, air bag time of deployment, level of air bag deployment, deployment of seat belt emergency tensioning retractors, seat belt forces, door openings, presence or absence of fire, pre-crash speed, and braking deceleration.

Occult Injuries – Occult injuries cause problems in providing timely optimal care. This section of the paper describes work by NHTSA and CIREN researchers to improve detection and treatment of serious occult injuries.

Brain injuries, especially the so-called “talk and die” injuries, are a constant concern to emergency medical care providers. As described in *Advanced Trauma Life Support Program for Doctors (ATLSPD)*:

“Despite proper attention to all aspects of managing

the patient with a closed head injury, neurologic deterioration can occur, often rapidly. The lucid interval commonly associated with acute epidural hematoma is an example of a situation where the patient will ‘talk and die’.” Diagnosis can be made more difficult by other circumstances, e.g., *“Alcohol and/or other drugs also may alter the patient’s level of consciousness.”* [56]

Thoracic injuries including lung, heart, and aortic injuries, without initial bleeding, can be fatal later. To overcome difficulties in diagnosis, the ATLSPD advises *“Contusions and hematomas of the chest wall should alert the doctor to the possibility of occult injury.”* It also warns of the pitfalls to be avoided regarding elderly and pediatric patients:

“A. Elderly patients are not tolerant of even relatively minor chest injuries. Progression to acute respiratory insufficiency must be anticipated and support instituted before collapse occurs.”

“B. Children often sustain significant injury to the intrathoracic structures without evidence of thoracic skeletal trauma. A high index of suspicion is essential.” [56]

Internal bleeding injuries in the abdomen without external symptoms e.g., liver, spleen, and bowel injuries have long been a concern in emergency medical care of crash victims. As the ATLSPD describes the problem: *“Abdominal injuries must be identified and treated aggressively....A normal initial examination of the abdomen does not exclude a significant intra-abdominal injury...Knowledge of injury mechanism, associated injuries that can be identified, and a high index of suspicion are required.”* [56]

Occult Injury Warnings - To advance *“the detection and evaluation of damage”*, the nation’s first Occult Injury Database (OID) was developed by researchers at the CentTIR, NHTSA, and CIREN [19]. The OID is a new tool for studying the problem of occult crash-related injuries that often can be fatal. Occult injuries can be fatal because of their severity, time sensitivity, and treatment criticality.

For the purposes of this database, occult injuries are defined as injuries that are not easily recognized and are life-threatening. They require timely treatment at the scene, in transport, and at medical facilities and trauma centers that are equipped and staffed to provide optimal care.

Occult injuries present difficulties at all stages of care: triage, transport, and treatment decision-making. Crash victims may decline medical treatment, despite needing care, because they “look

and feel OK.” Many factors complicate diagnoses of crash injuries. In multiple injury cases, common in crashes, the pain of one injury may distract the patient from pain of another more serious injury. Or the presence of alcohol may impair the ability of the patient to provide proper responses during medical examination. Occult injuries also are often characterized by deterioration at differing rates. Initially, such injuries may not be apparent. However, if not properly treated, victims can deteriorate, sometimes rapidly, and too often suffer fatal consequences.

The OID was used to estimate, also for the first time, the potential number of fatalities occurring each year from occult injuries to occupants in motor vehicle crashes. The estimates indicate that in an average recent year, 1,186 crash-related fatalities were recorded with a potentially occult injury as the “Only Cause of Death.” In addition, based on data from 1997-2001, the estimates are that, in an average year, of 29,118 injuries recorded as a “Cause of Death,” 18,888 were potentially occult injuries.

Thus, nearly 65 percent of all the fatal injuries recorded as a cause of death to occupants in crashes each year were due to potentially occult injuries. The approximately 18,888 potentially occult injuries recorded as a Cause of Death each year were distributed by body region as follows: 10,376 head, 6,001 thoracic, and 2,511 abdominal and pelvic injuries. Of the 1,186 single Cause of Death cases, 441 were head, 658 thoracic, and 87 abdominal/pelvic. [19] See

http://www.cubrc.org/centir/occult_injury.html

Crash information may be used to improve triage and treatment decision-making by helping in the identification of occult injuries. [54-55] Researchers at the CIREN centers and NHTSA have found that use of information from the crash has the potential of providing more sensitive triage and faster diagnosis of injuries for motor vehicle crash victims.

One of the first contributions on occult injuries by current NHTSA/CIREN researchers occurred after the advent of air bags. While air bags protect the head and face in serious crashes, internal injuries are being missed. This happens because the previously common “tell tale” signs of bleeding from facial lacerations and decreased levels of consciousness are now often not present to alert emergency medical care providers to the severity of the crash.

This new injury pattern led NHTSA to issue a *Research Note* “Detection of Internal Injuries in Drivers Protected by Air Bags” to help emergency medical care providers better recognize occult

internal injuries. That *Research Note* recommended that rescue workers “lift the deployed air bag to look for steering wheel deformation.” [21]

This “Lift and Look” tip to make a quick visual check was made to reduce the likelihood that potentially fatal internal injuries would be missed because motorists protected by air bags “may look fine and feel fine, but not be fine.” Occult internal injuries from blunt trauma often are survivable if detected and treated appropriately in time.

Consequently, NHTSA published and widely distributed the poster “Look Beyond the Obvious” based on continued research at the Miami CIREN Center [22]. This research found additional occult injury patterns that could be recognized using information from the crash. The “Look Beyond the Obvious” poster listed five indicators based on crash scene information to help emergency care providers detect internal injuries. These were organized into a checklist in an easy to remember mnemonic SCENE:

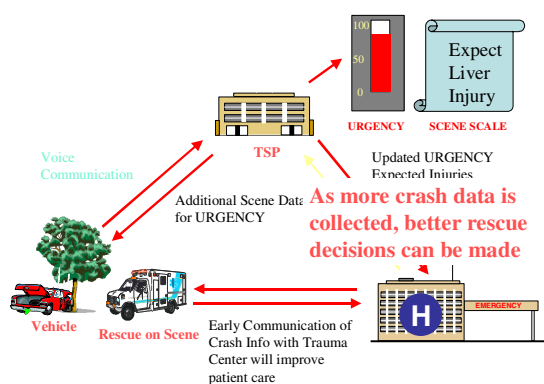
- **S - Steering Wheel Deformation** – Lift the air bag and look. A bent steering wheel could provide an alert that internal injuries are present.
- **C - Close Proximity of Driver to Steering Wheel** – Occupants of small stature or large girth sitting close the steering wheel are at greater risk of internal injuries.
- **E - Energy of the Crash** – Twenty (20) or more inches of vehicle crush, or twelve (12) inches of intrusion, indicate high-energy crash forces.
- **N - Non-use of Seat Belts** – Non-use of lap or lap shoulder belts by any of the occupants can result in multiple impacts of the occupants (including occupant to occupant loading) and greater probability of internal injuries. Note the non-use of lap belts continues to be of concern. The estimated number of vehicles on the roads today equipped with manual 2-point belts exceeds 10 million vehicles.
- **E - Eyewitness Report of Crash Scene** – Verbal reports, photos, and tele-video images of the crash vehicle convey some idea of the severity of the crash, and may indicate the possibility of occult injuries.

These recommendations on occult injury indicators are increasingly relevant. Today, the need to detect occult injuries is growing each year as more Americans are riding with their belts buckled (now 79%) and protected by air bags (air bags are now in more than 133 million vehicles, or 60% of the fleet). While air bags and seat belts are now estimated to

save nearly 17,000 lives each year, these post-crash tips can increase the number of lives saved. [20]

NHTSA/CIREN researchers have continued this work and identified a series of crash characteristics associated with occult injuries. [44] These researchers have developed the following “Warning Flags,” or tips, to alert first responders to crash conditions that result in increased risk of occult injuries and compelling injuries. Figure 14 schematically describes the information flow possible from the scene of serious crashes to EMS, hospitals, and telematics service providers (TSP) such as ATX, Cross Country Group, and OnStar. [18, 29]

Figure 14. Schematic of Improved Communications with Occult Injury Warning Flags



NHTSA CIREN researchers have worked for years to identify the characteristics of motor vehicle crashes that increase the risk of serious injury. This research resulted in the development of a mathematical algorithm (discussed above) to estimate the probability of the presence of serious injury in a car crash based on crash severity measures. The NHTSA CIREN research team incorporated the algorithm into computer software named *URGENCY* to relate crash severity measures to the probability of serious injuries. [11-18]

In addition to developing improvements in *URGENCY* for use with Automatic Crash Notification (ACN) systems, work has proceeded to develop *SCENE URGENCY* for use with handheld computers for use in all current crashes since most vehicles currently are not equipped with ACN systems. Field-testing of this software is planned.

Occult injuries comprise a fraction of all crash injuries and result in an unknown number of preventable deaths. In many cases the deaths might have been prevented had the injuries been recognized and treated in time. Independent studies funded by

NHTSA found a range of preventable deaths from 17% in rural Montana in a 1992 report [36], 12.9% in a rural Michigan study [37], and 7-21% in North Carolina in a 1995 report [38]. Occult injury warning flags, had they been available, may have helped improve system effectiveness.

Note that the preventable death studies just cited were performed before air bags were present in a large proportion of the fleet and at times when safety belt use was lower. In addition, these studies examined the problem of preventable deaths “as is.” They did not address how many additional deaths might have been preventable using new technologies providing information from the crash. Use of such crash information is expected to improve quality of care by alerting medical care providers to the potential for occult injury presence and reduce the risk of missed injuries.

CIREN researchers have identified potentially useful indicators of the presence of occult injuries. [44, 48] Several occupant and crash characteristics have been associated with an increased risk of serious injury. Each factor is being incorporated into developmental software as an “Occult Injury Warning Flag.” The following Warning Flags have been organized into a mnemonic OCCULT:

- **O -- Occupant Age & Sex** – Older adults have a higher risk of suffering serious injuries than younger adults in a crash of the same crash severity (in all crash directions combined). [15, 44, 63]

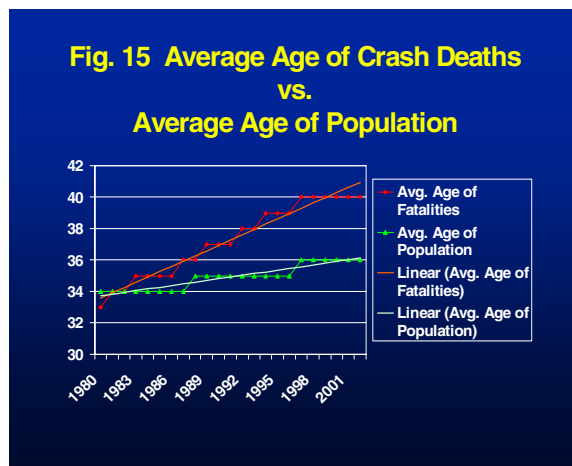
For example, in a 35 mph frontal impact crash, a 25 year-old male has about a 41 percent probability of suffering a serious injury. In a crash of the same type and severity, a male age 75 faces a 74 percent probability of being seriously injured. Thus, independent of the vehicle damage, occupant age should be taken into account in assessing the probability of serious injury. [16]

Females in a crash of a given severity also face a greater risk of suffering serious injuries than do males. For example, if the occupant in a 35 mph frontal crash is a female, instead of a male as in the above crash; at age 25 her risk of serious injury is about 45 percent.

The overall risk of serious injury in a crash of a given severity increases at a rate of nearly 1 percent per year of age through the adult years.

Figure 15 below provides data indicating the growing importance of age in the nation’s crash problem. As the U.S. population ages, the

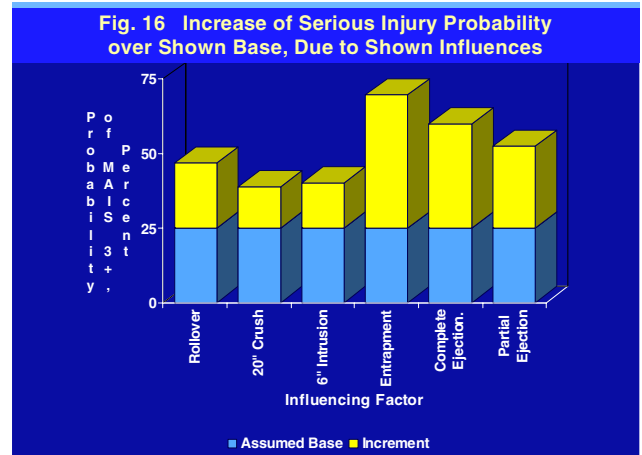
average age of crash fatalities has increased steadily over the past 20 years. Note, however, that while the nation's average age of the population has increased from 34 to 36 since 1980, the average age of crash fatalities has increased at a greater rate from 33 to 40.



Currently, more than 10,000 people, age 55 and older, are killed in crashes each year. In the near future, demographics indicate that the importance of age in crashes will grow rapidly. The U.S. population age 65 and older is projected to increase from 35 million in 2000 to 63 million by the year 2025. [40]

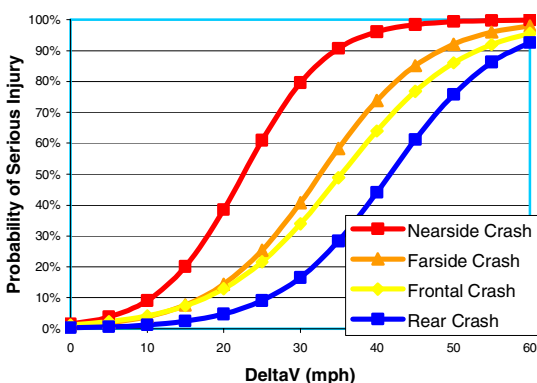
Researchers at the Alabama CIREN Center recently published a paper concluding that "Older adults have the highest rate of motor vehicle collision-related blunt aortic injury (BAI), and their injuries tend to occur in less severe collisions. A high level of suspicion for BAI among older adults should not be reserved for high-energy collisions only." This underscores the importance of faster and more informed transport and treatment decision-making that takes into account the age of the crash victims. [41-43]

- **C – Caught or Entrapped** – As is shown in Figure 16, if an occupant is entrapped in the vehicle, the risk of serious injuries nearly triples to close to 75 percent from an assumed baseline crash with a 25 percent probability of a serious injury. Thus, entrapment is a warning flag that serious injuries are likely in that crash. [15, 44]
- **C – Complete or Partial Ejection** – Also as can be seen from Figure 16, if ejection is involved in a crash, the probability of serious injury approximately doubles to more than 50 percent probability of serious injury. [15]



- **U – Under-ride and Narrow Object Crashes** – Crashes that involve under-ride of another vehicle or impacts with poles, trees, and other narrow objects increase the likelihood of internal and other serious injuries. These crashes may involve increased belt loads and late deployment of air bags that result in less than optimal crash protection. Part of the physical crash problem here is that vehicle crash sensors may sense crash forces late (milliseconds later) in these crashes. Thus, the occupant may be less optimally positioned to obtain maximal protection from the restraint systems and suffer internal injuries. [44]
- **L - Lateral Crashes, Near Side, Far Side and Off-Side Crashes** – As Figure 17 indicates, the risk of serious injury is very dependent on crash type. Note that side impacts, of a given crash severity, have the highest risks, with near side impacts having the highest risk of serious injury. For instance, in crashes with a 30 mph Delta V, occupants struck on the near side have an estimated 80% risk of suffering serious injury. Far-side occupants have nearly a 50% risk. Occupants in 30 mph frontal crashes have nearly a 40% risk. And occupants experiencing a rear impact crash with a 30 mph Delta V have about a 20% risk. Note that crash force direction can result in four-fold to six-fold differences in probability of serious injury. [44]

Figure 17 - Probability of Serious Injury by Crash Direction and Severity



Crashes in which the vehicle is struck from the side, or off-side at one of the wheels, may result in rapid rotation of the vehicle and cause occupants to suffer internal injuries that are asymptomatic and not apparent e.g., aortic, abdominal, and spinal injuries.

- **T – Two or More Impacts** – Crashes that involve multiple impacts such as vehicle-to-vehicle followed by an impact with another vehicle or structure increase the risk of serious injuries. Crashes involving multiple impacts may induce complex loading of the chest, abdomen, and spine. [44]

With ACN and *SCENE URGENCY* software and Occult Injury Warning Flags, the outcomes of many serious crash injuries are expected to improve. These new tools will enable better outcomes with improvements in the timeliness, appropriateness, and efficacy of the medical care received by the crash victim. In too many cases, especially in rural areas, people die without having obtained definitive care at a trauma center within the "Golden Hour." Definitive care for seriously injured crash victims includes expert care at the scene and en route, thorough, timely, and accurate diagnoses, intensive critical care facilities, and readily available trauma teams with surgeons specializing in brain, spinal cord, internal organ, and orthopedic injuries.

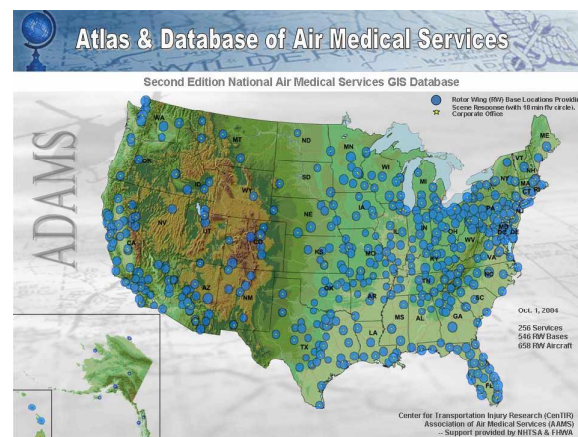
ADAMS for More Timely Rescues – To advance the ability to provide timely, quality, emergency medical care, the researchers have developed the nation's first Atlas and Database of Air Medical Services (ADAMS). See

<http://www.adamsairmed.org/>

ADAMS was developed to facilitate, in Dr. Haddon's

words "*the decision to follow-through,*" the deployment of air medical services to rescue people in serious injury crashes.

Fig. 18 Atlas & Database of Air Medical Services (ADAMS)



The national view of ADAMS is shown in Figure 18. ADAMS is designed to improve the timeliness and quality of emergency response and care. Research that led to ADAMS is at [18, 23, 25-29, 46, 49, 58-60].

Currently in virtually all 42,000 deaths and 250,000 serious injuries every year, helicopter rescue operations do not begin unless, and until, someone in authority (usually police, fire or EMS) travels over land to the crash scene to make a judgment to call for air medical rescue. Consequently today, too often, the deployment of appropriate rescue resources results in the dispatch of too little, too late, to save lives and prevent disabilities. Without the tools described in this paper there also is a substantial amount of over-triage currently occurring.

Current national data on air medical rescues is too scarce to quantify how many seriously injured people in crashes might have benefited from the more-timely and often higher level care provided by air medical rescue teams both at the scene and en route to the trauma center.

Better utilization of air medical services can produce reductions in mortality and morbidity of crashes. Such benefits can be achieved with faster response and transport times, higher quality care at the scene and in transport, and at the highest-level trauma center. The goal is to facilitate air medical care when needed, and avoid over utilization when not needed.

To fully reap the safety benefits of ACN technology for seriously injured crash victims, information on the crash must be provided to the appropriate emergency responders as soon as possible. By

A detailed survey of air medical services was conducted including the specific location of all air medical bases and Rotor Wing (RW) aircraft in the country. This detailed assessment of air medical rotor wing service coverage areas across the nation was used to produce ADAMS [29].

Using ADAMS in concert with ACN and *URGENCY*, the researchers believe that the nation is now better equipped for processing “*the signal’s transfer, receipt, and evaluation*,” and making “*the decision to follow-through*” for seriously injured crash victims. In the near future, using crash-specific information from the ACN signal and using *URGENCY* to interpret the injury implications of the signal, dispatchers will be able to rapidly assess the need for an air medical response. With ADAMS, air medical services will have the ability to be on early alert, as will the nearest trauma centers. It is expected that the near-parallel (rather than serial) response which ensues, will enable appropriate responders to reach the scene sooner after the crash than is currently possible.

In addition to being designed as a tool to improve operations; ADAMS is designed to be a research tool to find ways to continuously improve emergency care. ADAMS is contributing to research by the Association of Air Medical Services (AAMS). The AAMS Research Committee currently is examining the potential of using Auto Launch/Early Activation policies to improve emergency medical care to seriously injured people. [64]

available to analysts collecting data for national crash databases. In the near future, mode of transport (ground, air, or some combination) as well as the air medical service utilized will be easily recorded in the crash data record along with the location and type of hospital or trauma center to which the patient was transported. ADAMS will therefore enable national crash databases to document *how* crash victims were transported as well as *where* they were transported to. In addition, accurate crash times (from ACN crashes) can be coupled with the time data already collected in the national databases (time of EMS notification, scene arrival, hospital arrival, etc.).

Air Medical Coverage Relative to Fatal Crash Locations

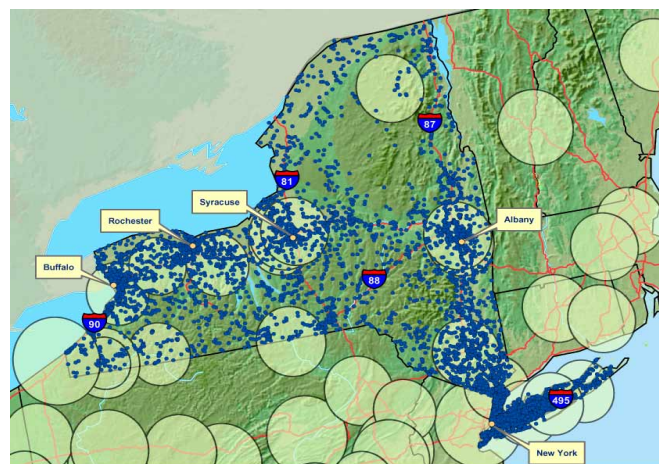


Figure 19 shows a map of NY with the locations of all fatal crashes between 1996 and 2001 indicated by a blue dot. This data was geo-coded using specialized software developed by Drs. Hwang and Thill at the Department of Geography at the State University of NY at Buffalo. [67]

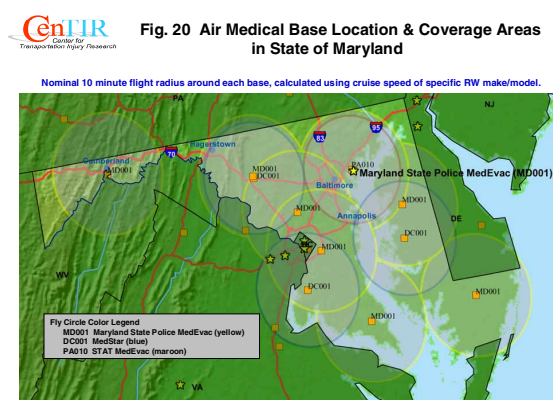
Analyzing fatality data in a geographic context enables researchers to easily view where crashes are occurring and aids in characterizing the nature of

these events in each region (e.g., are they predominantly in urban, suburban, or rural areas, are they on or off the major highways, are they overly concentrated in specific locales that could benefit from better use of air medical services, etc.?)

An additional overlay on the map in Figure 19 shows the air medical base locations with 10 minute fly circles. With ADAMS it is possible to perform even more detailed analyses of air medical coverage patterns. The number of crashes that occurred within 10- minute fly-circles in NY State between 1996 and 2001 were calculated. The data indicates that 75-78% of the fatal crashes occurred in areas that were within a 10-minute fly-circle.

Nationwide, about 70 percent of the population is located within 10-minute fly circles in the U.S. and about 97 percent within 30-minute fly circles. In contrast, about 33 percent of the interstate and U.S. highway system is located within 10-minute fly circles in the U.S.; and about 82 percent of these roads are within 30-minute fly circles. [29]

Figure 20 shows an ADAMS map of Maryland's air medical system with 10-minute fly zones. This illustrates the possibility of rescues within the "Golden Hour" in the future with ACN, *URGENCY*, and ADAMS. An ACN signal is translated into a high *URGENCY* rating alerting the statewide trauma care system. EMS and heavy rescue teams arrive within the "Golden 10 minutes". Air medical arrives. Patient(s) extricated by 30 minutes after the crash. Within 45 minutes post-crash, patient(s) arrive at trauma center. Patient receives definitive care in the Operating Room within "Golden Hour" post-crash. The result will be lives saved and disabilities prevented.



Conclusions -- New technologies are available to:

- (a) rapidly detect and evaluate damage with ACN,
- (b) alert emergency medical care providers with

URGENCY software and Occult Injury Warning Flags,

- (c) enable earlier and more informed dispatch decisions, including air medical services,

to rescue people seriously injured in crashes - in time to save lives and prevent disabilities. The lifesaving and disability-reducing capabilities of these new technologies will help build a safer America.

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PATTERNS OF INJURY SEVERITY AND ITS LIKELIHOOD IN TWO-VEHICLE CRASHES

Santokh Singh and Eun-Ha Choi

Mathematical Analysis Division

National Center for Statistics and Analysis

United States Department of Transportation

400 Seventh Street, SW, Washington, DC 20590

Paper No. 05-0252

ABSTRACT

Understanding injury severity patterns in roadway crashes is important not only from the view point of treating crash victims, but also for directing the crash avoidance efforts of traffic safety agencies and motor vehicle manufacturers. The factor that is most discussed in this context is vehicle incompatibility. However, there are other vehicle-, occupant-, and roadway-related factors, too, that play roles in injury severity.

In order to investigate these factors in relation to the injury severity, this paper considers a two-vehicle crash as a 'system' with its elements: vehicles, drivers, and roadway. Some of the possible inputs (contributing factors) to this system are considered with a focus on injury severity of the driver as an outcome. The differences in weights, heights, and shapes, etc. of the crash-involved vehicles, vehicle speed, drivers' ages and genders are the factors in question. Data mining the crash databases compiled by the National Highway Traffic Safety Administration (NHTSA) makes many important revelations. The association between the subject variables and driver injury severity is studied through contingency analysis. Configuration frequency analysis helps to identify patterns of injury severity. The main objective of the study is achieved by building a logit model that can be used to predict the likelihood of injury severity from a given set of vehicle-, driver-, and roadway-related crash characteristics.

INTRODUCTION AND RATIONALE

Reducing crashes on the roadways is of paramount importance, as is the reduction in crash injury severity. Many studies have been conducted on injury severity [e.g., 5,9]. Most of them are based on controlled experimentation and look at the phenomenon purely from an engineering or medical point of view. One of the reflections of these studies

is that vehicle incompatibility contributes to injury severity in a crash [6]. In other words, the larger differences in the sizes and weights of the crash-involved vehicles are likely to result in more serious injuries to occupants of the smaller vehicle.

Injury and its severity is the resultant effect of collision between two bodies (vehicles). Therefore, in order to study the magnitude of this effect, crash phenomenon must be looked at as an impact, i.e., the effect of transfer of energy from one vehicle to the other [7]. This results in change of relative velocity. As kinetic energy [$=\frac{1}{2}(\text{Mass} \times \text{Speed}^2)$] increases with square of velocity, the energy of motion of the striking vehicle dissipated to the other vehicle increases not only with the increasing mass but also with the increasing velocity.

The vehicle occupants acquire the same velocity as the vehicles they are riding. Thus, while the colliding vehicles undergo changes due to conservation of momentum generated by the impact, their occupants, too. Also, the roadway conditions, to a large extent, govern the last moment changes, such as velocity change, etc. This makes it imperative in an injury severity related study to consider the vehicle, occupants, and roadway together. Following this rationale, a crash is considered as a system with interacting elements: Vehicles, Occupants, and Roadway.

An object with small inertial mass changes its motion more readily than an object with large inertial mass. This argument applies to both the vehicles in crash and their occupants. This shows that for injury severity, if vehicle mass is a contributing factor, so is the occupant body mass. In fact, each element of the crash system has certain associated characteristics that contribute to the outcome (injury severity) of this system. Using multivariate statistical methods, this paper explores factors that contribute to injury severity. Injury severity patterns are identified as well

as a model is developed to predict the likelihood of injury severity.

The current analyses focus only on the injury severity of the drivers involved in two-vehicle frontal crashes. In the subsequent discussion, the term crash will refer to such crashes only. Also, the term ‘occupant’ and ‘driver’ will be used interchangeably, though always referring to driver and the term ‘car’ will be used for a ‘passenger car.’

DATA SOURCE AND MANIPULATION

NHTSA compiles data on automated, comprehensive national traffic crashes and maintains: National Automotive Sampling System (NASS)-Crashworthiness Data System (CDS) database. The NASS-CDS database provides detailed information about vehicle-, driver-, and roadway-related variables. In the subsequent discussion, this database will be referred to as CDS. The results presented in the following sections are based on the CDS data for the years 1995 through 2003.

The data used in the subsequent analyses is extracted from the CDS database by including only the frontal crashes (manner of collision=head-on) and using other restrictions: the number of crash involved vehicles (=2) and the occupant role (=driver).

ANALYSIS VARIABLES

Once injury severity is considered as an outcome of the crash system, many variables become candidates for evaluation. From the earlier discussion, however, it follows that vehicle body type, speed and change in velocity are important vehicle factors. Similarly, in order to take into account the driver’s response to changes that occur due to impact, occupant’s body mass (weight and height), age, and sex need to be considered, too. Road surface condition is another possible contributing factor. Thus, the crash system can be considered as an input/output system as presented in Figure 1, with the above factors as inputs and injury severity as outcome.

As an aid to select appropriate CDS variables and for the sake of clarity in the subsequent discussion, some terms are explained below.

Vehicle Incompatibility: Vehicle incompatibility between two colliding vehicles is defined in terms of the difference between their weights, heights, and shapes, etc.

Using this definition in the context of impact, it may be inferred that the difference between masses of two

colliding vehicles is one of the factors contributing to the extent of vehicle damage. For example, a sports utility vehicle or a light truck with large mass is likely to cause much more serious damage in a crash to a vehicle of smaller mass such as a sedan.

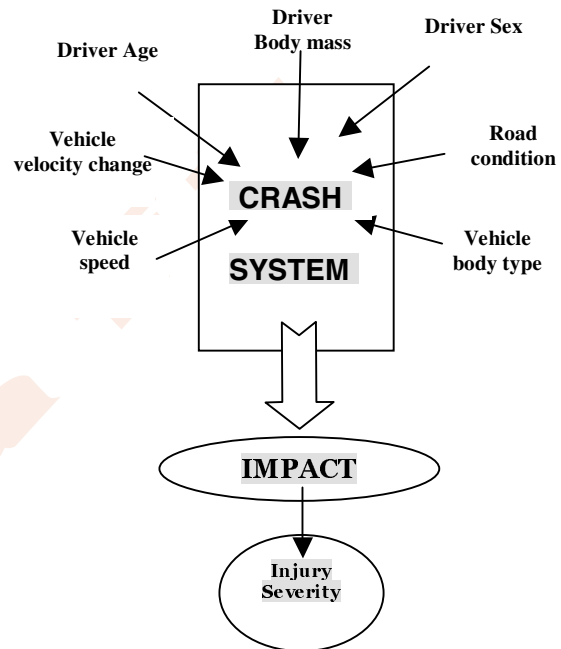


Figure 1. Crash as an Input-Output System

The variable in the CDS crash database that takes into account such vehicle parameters is the vehicle body type. Accordingly, the difference in the body types of crash vehicles is used to account for vehicle incompatibility. The two vehicle body types colliding in a crash will be referred to as ‘crash configuration.’ For example, a passenger car colliding with a light truck defines a crash configuration: car vs. light truck.

Body Mass Index: Body Mass Index (BMI) is a composite number assigned to a driver based on his/her weight and height and is given by [3]

$$BMI = \left(\frac{\text{Weight}}{\text{Height}^2} \right) \times 10,000 .$$

Based on these two driver characteristics, this number accounts for the response of the driver to forces that occur due to instant changes in an impact.

Injury Severity Score: Injury Severity Score (ISS) of an occupant is an anatomical scoring system that provides an overall score for patients with multiple

injuries [2]. This scoring system depends on Abbreviated Injury Score (AIS). Of the six body regions, head, face, chest, abdomen, extremities, and external, AIS values for the three most severely injured body regions, say, B_1, B_2, B_3 , are used in calculating ISS. Specifically, Injury Severity Score of a driver is given by

$$ISS_D = (AIS_{B_1})^2 + (AIS_{B_2})^2 + (AIS_{B_3})^2.$$

Driver Injury Severity: Driver Injury Severity (DIS) in a two-vehicle crash is the larger of the two ISS values assigned to drivers, D_1, D_2 and is given by

$$DIS = \text{Max} (ISS_{D1}, ISS_{D2}) .$$

Based on these definitions, the following CDS variables associated with the three crash system-elements are considered in the analysis.

Vehicle-related variables: In order to take into account the impact-related vehicle characteristics, the CDS variables: *Body type*, *Travel speed*, and *Total Delta-V* are considered.

Driver-related variables: Since the response variable DIS is considered as the resultant effect of impact, the possible driver-related CDS variables: *Age*, *Sex*, *Height*, and *Weight* are used in the analysis.

Roadway-related variables: In this category, the CDS variable thought to have some bearing on the crash and hence on injury severity is the *Road Condition*.

To establish association of the selected variables with DIS and identify its patterns, these variables are categorized as shown in Table 1. This table presents the CDS variables, the categorization criteria and the resulting categories.

ANALYSIS AND RESULTS

Depending on the hypothesis of interest, mainly three methods are used in the analysis: Configuration Frequency Analysis (CFA), Contingency Analysis (CA), and Logistic Regression (LR). CFA is conducted to statistically assess the extent to which vehicle incompatibility (in terms of body type) can explain the differences in injury severity that are observed in the data [1]. LR provides estimates of the relative likelihood of injury severity [4]. For building an LR model, the predictor variables are initially screened by CA [8]. Statistical software SAS 8.2 and SUDAAN 8 are used for these analyses.

Table 1.
Categorization of Analysis Variables

VARIABLE	CRITERION	CATEGORIES
DRIVER INJURY SEVERITY	Injury Severity Score	1: 0-5, 2: 6-10, 3: 11-30, 4: 31-50, 5: 51 and above
SEX	Pregnancy (P)	Male, Un-pregnant Female, Pregnant Female
AGE	Driver age in years	14-25, 26-35, 36-45, 46-54, 55-64, 65 and above
HEIGHT WEIGHT	Body Mass Index (BMI)	0-18.5, 18.6-24.9, 25 and above
VEHICLE INCOMPATIBILITY	Body Types of vehicles	† C-C, C-UV, C-LT, UV-UV, UV-LT, LT-LT
TRAVEL SPEED	Vehicle Travel Speed	0-60, 61-75, 76-90, 91 and above
VELOCITY CHANGE	Total Delta-V	5-25, 26-35, 36-45, 46-55, 56-65, 66 and above
ROAD CONDITION	Road Surface Condition	Dry, Wet, Snow/Slush, Ice,

† C: Car, UV: Utility Vehicle and Van, LT: Light Truck

Configuration Frequency Analysis

CFA is a multivariate statistical technique that identifies those sectors of the data where the local associations are prominent. The method compares the observed to expected frequencies in a cross-tabulation. The goal of this comparison is to determine whether the difference between the observed and expected frequency for a given cell configuration is larger than some critical value and is statistically significant. Any significant difference between the observed and expected frequency for a configuration indicates that in that particular sector of the data space, the variables are (locally) associated with each other, thereby showing patterns in the data.

Table 7 (Appendix) shows the observed (weighted) and expected frequencies for each combination of crash configuration and DIS. Based on this joint frequency distribution, CFA results presented in Table 2 show that for driver injury severity of the lower order (DIS=1), the observed frequency of crashes involving two cars is much higher than the expected. This shows that on the average a driver of a car involved in a crash with another car: Car vs. Car would mostly sustain minor injuries. This pattern is also observed for the crash configuration: Utility Van vs. Light Truck, where the incompatibility is relatively low. In contrast, the difference between the observed and expected frequencies for crash

configuration: Car vs. Utility Van or Car vs. Light Truck is higher for higher DIS. Thus, the results of CFA (Table 2) show that as body type of the vehicle colliding with a Car changes from a Car to UV and from UV to LT, more than expected crashes are observed to be resulting in higher DIS. The deviation from this pattern for some configurations as observed in the CFA results is indicative of the possible effects of other driver- and roadway-related factors. The selection of such factors for predictive modeling is done by CA in the following section.

Table 2.
Configuration Frequency Analysis:
Driver Injury Severity vs. Vehicle Incompatibility
(Crash Configuration)

VEHICLE INCOMPA- TIBILITY	DRIVER INJURY SEVERITY				
	1	2	3	4	5
C [†] x C (1, 1)	5014	-1072	-2484	-859	-599
C x UV [†] (1, 2)	-3176	2238	377	-50	611
C x LT [†] (1, 3)	-1341	-1896	2217	774	247
UV x UV (2, 2)	103	132	-235	73	-73
UV x LT (2, 3)	1122	-387	-566	-63	-106
LT x LT (3, 3)	-1722	985	691	126	-80

[†] C: Car, UV: Utility Van, LT: Light Truck

Data Source: NASS-CDS (1995-2003)

Contingency Analysis

CA is conducted to test associations between the response variable, Injury Severity and other variables mentioned earlier. DIS as assessed by ISS is categorized in five categories, while for other variables the categories defined in Table 1 are used in the analysis. The results are presented in Table 3. These results provide strong statistical evidence, with significant χ^2 (95% confidence level), that DIS is closely associated with *Vehicle travel speed* and *velocity change*; *Driver age*, *sex*, and *body mass*; and *Road surface condition*.

Logistic Regression Model

Finally, a model is developed using LR modeling. This is a technique by which a functional relationship is established between a categorical response variable and the covariates.

Table 3
Contingency Analysis:
Significance of Association Between Injury
Severity and Vehicle-, Driver-, and Roadway-
Related Variables

VARIABLE	CHISQR (D. F.) *	ASSOCIATION WITH DIS
SEX	23.70 (7)	Highly significant (95% confidence)
AGE	1.09 x 10 ⁴ (15)	Highly significant (95% confidence)
BMI	68.24 (8)	Highly significant (95% confidence)
TRAVEL SPEED	7.2 x 10 ³ (11)	Highly significant (95% confidence)
VELOCITY CHANGE	1.55 x 10 ⁴ (15)	Highly significant (95% confidence)
ROAD CONDITION	2.07 x 10 ⁴ (12)	Highly significant (95% confidence)

*Degrees of Freedom

Data Source: NASS-CDS (1995-2003)

LR applies maximum likelihood estimation after transforming the dependent variable into a logit variable (the natural log of the odds of the dependent variable value occurring or not). In this way, LR model estimates the likelihood of a certain event occurring.

In the context of LR model, it is important to note that, based on ISS, the response variable DIS is polytomous, i.e., it assumes five values, depending on the range of ISS (Table 1), rather than two values as in the case of a dichotomous variable. Added to this is its ordinal (scale-based) nature. Therefore, an appropriate model for the current situation would be what is called Baseline Logit model [4]. Under this model, the logits are given by

$$g_k(x) = \ln \left[\frac{\pi_k(x)}{\pi_0(x)} \right] = \beta_{k0} + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_K x_K + \beta_{121} x_1 x_2 + \dots + \beta_{K \times K-1} x_{K-1} x_K.$$

In this model, the coefficients provide log-odds comparing category Y=k to a baseline category, Y=0, where Y represents the response (DIS in the present study).

Logit Model

All predictor variables found to be significantly associated with DIS and all possible two-way interactions are considered for fitting the logit model.

The results of LR modeling are presented in Table 4, 5, and 6. All test statistics provide strong evidence of goodness of fit of the model (Table 4).

Table 4.
Logistic Regression Results

MODEL FIT STATISTICS			
CRITERION	INTERCEPT AND COVARIATES		
AIC	9.29 x 10 ⁴		
SC	9.30 x 10 ⁴		
-2 Log L	9.28 x 10 ⁴		
TESTING GLOBAL NULL HYPOTHESIS: BETA=0			
TEST	CHISQR	DF	P-VALUE
LIKELIHOOD RATIO	4.9 x 10 ⁴	22	0.000
SCORE	3.7 x 10 ⁴	22	0.000
WALD	2.8 x 10 ⁴	22	0.000

Table 5.
Logistic Regression:
Analysis of Effects and Interactions

VARIABLE/ INTERACTION	CHISQR (D. F.) [†]	SIGNIFICANCE IN THE MODEL
VELOCITY CHANGE * VEHICLE INCOMPATIBILITY	8.3 x 10 ³ (5)	p-value << 0.05 Highly significant
AGE * SEX	6.5 x 10 ³ (2)	p-value << 0.05 Highly significant
AGE * BMI	6.6 x 10 ³ (1)	p-value << 0.05 Highly significant
VEHICLE INCOMPATIBILITY	8.0 x 10 ³ (5)	p-value << 0.05 Highly significant
SEX	5.8 x 10 ³ (2)	p-value << 0.05 Highly significant
AGE	120.4 (1)	p-value << 0.05 Highly significant
BMI	5.0 x 10 ³ (1)	p-value << 0.05 Highly significant
TRAVEL SPEED	163.0 (1)	p-value << 0.05 Highly significant
VELOCITY CHANGE	7.7 x 10 ³ (1)	p-value << 0.05 Highly significant
ROAD CONDITION	2.9 x 10 ³ (3)	p-value << 0.05 Highly significant

[†] Degrees of Freedom

<< much less than

Data Source: NASS-CDS (1995-2003)

Results in Table 5 show that of all the variables considered in the model, the main effects: Vehicle Incompatibility (in terms of body type), Travel Speed, Total Delta V, Driver Age, Sex, and BMI are found to be highly significant predictors (with p-values much less than 0.05). However, among all possible interactions considered in the model, the only interactions that are found significant (95% confidence level) are: Age* BMI, Age*Sex, and Vehicle Incompatibility*Total Delta-V. Finally, the estimates of the model coefficients and their

interpretation based on log odds are presented in Table 6. Along with these interpretations for significant main effects and interactions, this table also provides standard errors and p-values of the model coefficients.

CONCLUSIONS AND RECOMMENDATIONS

The baseline logit model with Injury Severity as the response variable and Body Type, Velocity Change, Body Mass Index, Age, Sex, and Road Condition as explanatory variables passed the adequacy test. The significance of all main effects in the model and some interactions provides strong evidence that driver injury severity can be explained by considering the vehicle-, driver-, and roadway-related variables together. In other words, the characteristics of these crash system elements are the contributing factors for the maximum injury severity of a driver in a two-vehicle frontal crash.

As regards patterns of injury severity, there are large sectors of the data space where driver injury severity is low for small or no body type difference, such as Car * Car, or UV * LT. Significantly large sectors of the two-vehicle frontal crash data are also identified where higher levels of DIS are observed for greater body type differences.

Restricting an injury severity study only to colliding vehicles, to their drivers, or to roadway can provide only partial information about crash injuries and their severity. The interactions between these crash elements, too, are significant. In order to fully understand the reason why in certain situations drivers sustain more severe injuries as compared to others, a study must consider all these elements together.

The results reported in this paper are relevant for driver injury severity in frontal two-vehicle crashes. More research is required, using the same system study approach, to investigate occupants' injury severity depending on their seating positions in the vehicle. Similarly, injury severity in multiple vehicle crashes and that resulting from other types of collisions such as rear-end, sideswipe, etc. can provide more insight into the phenomenon of crash injury. Due to incomplete information for some categories of vehicles and the sample size problem arising therefrom, the model built in this study is based on the crash level information (i.e., the driver with maximum ISS and the corresponding vehicle in a crash). However, it may be worthwhile to develop a model at the individual level using other information sources.

Table. 6
Analysis of Maximum Likelihood Estimates of Parameters in the Fitted LR Model

EFFECT/ INTERACTION	ESTIMATE (SE)	P-VALUE	INTERPRETATION
INTERCENPT 1	-0.1499 (0.5741)	0.7940	Log odds of getting injury (at DIS=1) versus DIS=2,3,4, or 5 for pregnant female driver in a crash with VEHICLE INCOMPATIBILITY (LT-LT) on icy road condition (=LO1)
INTERCENPT 2	0.9495 (0.5741)	0.0981	Log odds of getting injury (at DIS=2) versus DIS=1,3,4, or 5 for pregnant female driver in a crash with VEHICLE INCOMPATIBILITY (LT-LT)) on icy road condition (=LO2)
INTERCENPT 3	4.5836 (0.5748)	0.0000	Log odds of getting injury (at DIS=3) versus DIS=1,2,4, or 5 for pregnant female driver in a crash with VEHICLE INCOMPATIBILITY (LT-LT)) on icy road condition (=LO3)
INTERCENPT 4	6.4596 (0.5775)	0.0000	Log odds of getting injury (at DIS=4) versus DIS=1,2,3,or 5 for pregnant female driver in a crash with VEHICLE INCOMPATIBILITY (LT-LT)) on icy road condition (=LO4)
AGE * SEX (male)	0.0951 (0.0163)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) males of all ages
AGE * SEX (female)	-0.0131 (0.0163)	0.4216	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to females of all ages
AGE * BMI	-0.0103 (0.0001)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to AGE and BMI
VELOCITY CHANGE * VIC [†] (C-C)	-0.019 (0.0016)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to VELOCITY CHANGE and VEHICLE INCOMPATIBILITY (C-C)
VELOCITY CHANGE * VIC (C-UV)	0.1142 (0.0015)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to VELOCITY CHANGE and VEHICLE INCOMPATIBILITY (C-UV)
VELOCITY CHANGE * VIC (C-LT)	0.0389 (0.0015)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to VELOCITY CHANGE and VEHICLE INCOMPATIBILITY (C-LT)
VELOCITY CHANGE * VIC (UV-UV)	-0.014 (0.0027)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to VELOCITY CHANGE and VEHICLE INCOMPATIBILITY (UV-UV)
VELOCITY CHANGE * VIC (UV-LT)	-0.223 (0.0048)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to VELOCITY CHANGE and VEHICLE INCOMPATIBILITY (UV-LT)
VELOCITY CHANGE	-0.1118 (0.0013)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to VELOCITY CHANGE
TRAVEL SPEED	-0.00651 (0.0005)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to TRAVEL SPEED
AGE	0.1816 (0.0166)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to AGE
SEX (male)	-3.3883 (0.5581)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to male SEX
SEX (female)	1.1846 (0.5595)	0.0342	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to females
BMI	0.389 (0.0055)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to BMI
VIC (C-C)	-0.1956 (0.0788)	0.0130	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to VEHICLE- INCOMPATIBILITY (C-C)
VIC (C-UV)	-5.2768 (0.0737)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to VEHICLE- INCOMPATIBILITY (C-UV)
VIC (C-LT)	-3.3836 (0.0740)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to VEHICLE INCOMPATIBILITY (C-LT)
VIC (UV-UV)	0.9458 (0.1429)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to VEHICLE INCOMPATIBILITY (UV-UV)
VIC (UV-LT)	13.2949 (0.2741)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to VEHICLE INCOMPATIBILITY (UV-LT)
ROAD CONDITION (dry)	0.1339 (0.0267)	0.0000	Increment for all types of log odds (LO1, LO2, LO3, LO4) due to dry ROAD CONDITION
ROAD CONDITION (wet)	-1.1806 (0.0299)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to wet ROAD CONDITION
ROAD CONDITION (snow/slush)	-0.6407 (0.0503)	0.0000	Decrement for all types of log odds (LO1, LO2, LO3, LO4) due to snow/slush ROAD CONDITION

[†]VIC: Vehicle Incompatibility

Data Source: NASS-CDS (1995-2003)

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APPENDIX

Table. 7
Joint Frequency Distribution of Driver Injury Severity and Vehicle Incompatibility (Crash Configuration) with the Corresponding Expected Frequencies

VEHICLE INCOMPATIBILITY	FREQ	DRIVER INJURY SEVERITY					Total
		1	2	3	4	5	
$C^{\dagger} \times C$ (1, 1)	Obsrvd.	83773	7686	10355	1030	838	103682
	Expctd.	78759	8758	12839	1890	1437	
$C \times UV^{\dagger}$ (1, 2)	Obsrvd.	48316	7964	8771	1186	1550	67787
	Expctd.	51492	5726	8394	1236	940	
$C \times LT^{\dagger}$ (1, 3)	Obsrvd.	47829	3571	10232	1953	1145	64731
	Expctd.	49171	5468	8015	1180	897	
$UV \times UV$ (2, 2)	Obsrvd.	4100	577	417	169	0	5263
	Expctd.	3998	445	652	96	73	
$UV \times LT$ (2, 3)	Obsrvd.	17096	1389	2037	320	186	21028
	Expctd.	15974	1776	2604	383	292	
$LT \times LT$ (3, 3)	Obsrvd.	4196	1643	1656	268	28	7791
	Expctd.	5918	658	965	142	108	
Total		205311	22830	33468	4926	3747	270281

\dagger C: Car, UV: Utility Van, LT: Light Truck
Data Source: NASS-CDS (1995-2003)

A METHOD TO ESTIMATE INJURY MEDICAL COST OF OCCUPANTS IN A CRASH TEST

Ching-Huei Lai

Ji-Liang Doong

Department of Mechanical Engineering

National Central University

Taiwan

Tso-Liang Teng

Department of Mechanical & Automation Engineering

Da-Yeh University

Taiwan

Chun-Chia Hsu

Department of Multi-media and Game Sciences

Lunghwa University of Science and Technology

Taiwan

Paper Number 05-0303

ABSTRACT

In a laboratory crash test, the injuries of occupants, such as Head Injury Criterion (HIC), N_{ij} , Combined Thorax Index (CTI) etc., can be obtained and transferred to the Abbreviated Injury Scale (AIS). The calculated AIS value usually represents the severity of injury and can be adopted to evaluate the safety of the test vehicle. However, the AIS cannot reflect the medical resources consumed due to various vehicles of different designs. This study presents a statistical method to estimate injury medical cost from the AIS value of an occupant in a crash test. A frontal impact case study is illustrated. Five steps are carried out as follows:

1. To link the following three Taiwan's databases by the individual identification number: crash data reported by police officers, hospital data recorded in the health insurance database, and death database.
2. To calculate AIS values by the diagnosis ICD-9-CM code written by doctors for each individual case.
3. To develop a statistical model to estimate medical cost from massive crash cases obtained in steps 2.
4. To simulate crash test for obtaining the injuries of occupant by using a validated finite element simulation model of Hybrid III 50th percentile male dummy. The injuries of occupant are then converted to AIS values.
5. To estimate the probable medical cost by the statistical model using the predicted AIS values from the crash test simulation.

INTRODUCTION

Crash test required in the standards like FMVSS 208 is expected to get the minimum safety protection of the test vehicle. In addition to evaluate the basic required safety criteria, a computer simulation test

can further predict the occupants' injury of slight changes in vehicle design and restrained features. On the other hand, the qualified vehicle models being driven on the road by different drivers in the real world would be involved in the crashes unavoidably. Then, data linkage technique could be used to link different real crash databases to explore more information between the real world and the crash test. In order to use the engineering variables of the dummy in the crash test to evaluate the injury type and severity of the occupants, the injury criteria such as Head Injury Criterion (HIC), N_{ij} , Combined Thorax Index (CTI) etc., can be obtained and transferred to the Abbreviated Injury Scale (AIS). The calculated AIS value usually represents the severity of injury. It can be obtained through biomechanical test-based injury risk functions (Kleinberger et al., 1998; Kuppa et al., 2001; Kuppa, 2004; Kuchar, 2001; Newman et al., 1994).

The biomechanical cost model proposed by Newman et al. (1994) utilized injury risk functions to predict the occurrence probability of different AIS scores to the head, thorax, and abdomen (Newman et al., 1994). For a particular body region, average medical and ancillary cost of a specific AIS score multiplied by its probability was used to forecast the probable cost of an injury.

Kleinberger et al. (1998) conducted an examination of biomechanical results and real world data in the frontal crash, and adjusted a set of logistic regression models of injury risk for the Hybrid III 50th percentile male dummy. The injury criteria used in their study were HIC36 (Head Injury Criteria) to head, N_{ij} to neck, CTI (Combined Thoracic Index) to chest, and Femur load to lower extremity. Also, Kleinberger et al. proposed risk functions $AIS \geq 3$ of neck N_{ij} and $AIS \geq 5$ of chest CTI. The risk function of head HIC36 $AIS \geq 2$ developed by Hertz in 1993 was presented in Kleinberger's study (1998).

A more complete Hertz's HIC36 risk functions including AIS ≥ 2 , AIS ≥ 3 , and AIS ≥ 4 were shown in the study of Kuppa (2004). Kuppa et al. (2001) used existing biomechanical data on lower extremity injuries and regression method to synthesize injury criteria and associated injury risk functions of AIS ≥ 2 . Kuchar (2001) also used HIC36 and CTI risk functions proposed by Kleinberger et al. (1998) in his systems modeling approach to assess harm in the crash environment.

The injury risk assessment of mechanical surrogate of human cannot predict the medical cost of the injury. But, the medical burden is a major concern of injury prevention in the real world. Rosman and Hendrie (2002) presented a process by using Injury Cost Database, and linked hospital admission and death records of Western Australia to study the real world characteristics. ICDMAP software developed by John Hopkins University was used to convert diagnosis codes to AIS score for different body regions. Then a linear regression model of total medical costs was built up. Hendrie et al. (2001) developed a generalized linear model (GLM) to estimate crash medical costs of the body regions and AIS injury scores by using Road Injury Cost Database of New South Wales, Australia. The results indicated that GLM model could explain 36% of the variation in the total cost of injuries in the Road Injury Cost Database. Lawrence et al. (2002) noted a significant low medical cost of the fatality showing a necessary to discuss them separately from the survivals. The fatality and the survivals had different probability cost models in the Newman's study (Newman et al., 1994) too.

Owing to the gap between injury assessment of biomechanical test and the medical burden concern in the real world, the AIS concept could be applied as a bridge to the gap. In the present study, real crash, hospital and death records of Taiwan are linked to develop a medical cost model of various crash injury severities. A validated finite element simulation model of Hybrid III 50th percentile male dummy is used to simulate injury in the crash test. Then the computer simulation outputs are substituted to the medical cost model to calculate the probable medical cost of the predicted injury.

METHODS

Medical Cost Model

Using real world data of Taiwan can develop a medical cost model. A lot of useful information in crash database, health insurance database, and death database can be found by data linkage technique.

Table 1 shows the data items used in the present study. The three databases all include an individual identification number (ID) to indicate whose data was recorded. The ID is a specified number issued by Taiwan's government when a baby was born. Therefore, it is possible to obtain associated data of a particular person by using data linkage technique via ID in crash, health insurance, and death databases. In the present study, crash and death records are linked via ID firstly, to separate survivals from the fatality. Then the IDs of the survivals are linked to health insurance database, to obtain their hospital treatments records and costs.

Table 1.
The data items used in the present study

Database	Data items
Crash	individual identification number (ID) victim type (driver, passenger etc.) crash type (frontal crash, side crash etc.) vehicle type (passenger car, bus etc.) crash occurrence date
Health insurance (hospital data)	individual identification number (ID) 3~5 ICD-9-CM codes treatment type (hospitalized, outpatient services, emergency treatment etc.) medical expenditure admission date
Death	individual identification number (ID) death date

Software ICDMAP 90 developed by the John Hopkins University and Tri-Analytics, Inc. can convert ICD coding system in the large pre-existing medical database to AIS coding system. The principle ICD-9-CM diagnosis code in each of Taiwan's injury hospital records is converted to the AIS score (1 to 6, 6 is for dead subject) and body region (1 to 10). Then, a new database can be generated, including victim type, crash type, vehicle type, medical expenditure, AIS score, and AIS body region data of each person involved in the crash.

Different crash types can result different probabilities of body regions injury. While a specific region injured, any severity is possible, and various degree of injury will have significant influence on the variety of medical cost. According to this causation, the equation of medical cost model is as follows:

$$C = \sum_{j=1}^n \sum_{i=1}^5 S_j P_{ij} C_{ij} \quad (1).$$

where

- i : is the level of injury, defined by AIS scores (1 to 5)
- j : is a particular AIS body region injured (1 to 10).
- S_j : is the probability of each body region j injured in a specific crash type, such as frontal crash.
- P_{ij} : is the probability of a particular AIS score i to a specific body region j .
- C_{ij} : is the medical cost of each body region j injured with AIS score i .

Logistic regression is used to develop the probability equations of S_j from real crash data in Taiwan. A mathematical relationship between the dichotomous dependent variable ('injury' and 'no injury') and independent variable (crash type) is estimated. Wald statistics Z^2 (coefficient β dividing its approximating standard error) and -2log-Likelihood Ratio are used to examine the significant of the coefficient and the goodness of fit of this logistic regression model respectively. Linear and non-linear regressions are used to calculate C_{ij} from Taiwan's real crash data. The AIS score is the independent variable, and medical cost is the continuous dependent variable. R^2 is used to examine the explanation ability of fitted C_{ij} equations. The P_{ij} are calculated directly from the injury risk functions proposed by Kleinberger et al. (1998), Kuppaa (2004), and Kuppaa et al. (2001).

Finite Element Simulation

Software LS-DYNA3D is used to simulate the dynamic responses of Hybrid III 50th percentile male dummy (regulations of FMVSS 49CFR PART 572E) restrained with a seatbelt (regulation of FMVSS 208) in a frontal impact sled test. The simulation model is validated according to Prasad's (1990) experiment results. In the present study, the test speed is 30mph (FMVSS 208 requirement). The impact on the head, neck, thorax, and knee of the simulation dummy is compared to the result of Khali's (1994) study. Injury criteria based on FMVSS 208 (HIC36 to head and N_{ij} to neck), NHTSA suggestion (CTI to thorax), and Kuppaa et al. (2001) result (force to femur) are calculated from simulation outputs.

Crash Injury Medical Cost Prediction

The injury criteria calculated in the above section are converted to the probabilities of various AIS scores by using the equations (2)~(5) which are the injury risk functions of mid-sized adult male based on biomechanical tests from the other studies. Except the seatbelt and the seat, there is no other interior equipment in the sled simulation model.

Therefore, the femur and the thorax of the simulated dummy cannot response reasonably in the simulation model. The associated injury criteria of femur and thorax are not calculated. In the future, this shortage can be overcome when the simulation model is upgraded from sled model to full vehicle model.

Head: (Kuppaa, 2004)

$$P(AIS \geq 3) = \phi\left(\frac{\ln(HIC_{36}) - \mu}{\sigma}\right) \quad (2).$$

$\mu = 7.45231, \sigma = 0.73998$
 ϕ : accumulative normal distribution

Neck: (Kleinberger et al., 1998)

$$p(AIS \geq 3) = \frac{1}{1 + e^{3.906 - 2.185 N_{ij}}} \quad (3).$$

Thorax: (Kleinberger et al., 1998)

$$p(AIS \geq 3) = \frac{1}{1 + e^{7.529 - 6.431 CTI}} \quad (4).$$

$$CTI = \frac{A_{max}}{A_{int}} + \frac{D_{max}}{D_{int}}$$

Femur: (Kuppaa et al., 2001)

$$p(AIS \geq 3) = \frac{1}{1 + e^{4.9795 - 0.326 F}} \quad (5).$$

The outputs of equations (2)~(3) are substituted into the P_{ij} in the equation (1), together with the associated S_j and C_{ij} stated in the above, to estimate the probable medical cost resulted from passenger car driver in the frontal impact.

RESULTS

Real Crash Data Analysis

There are 330 thousands crash victims reported by police in Taiwan from year 1999 to 2001. 7087 of them are found in the death records, 1118714 survived victims are successfully linked to hospital data. Among 1118714 survivals, 15177 are passenger car drivers. 7 of these 15177 drivers are assigned AIS = 6 by ICDMAP 90, 7182 drivers are in unknown injury state, and 7988 drivers are survived in AIS 1~ 5. Among 7988 survival drivers, 1737 drivers (21.7%) are involved in the frontal crashes. It can be seen in Table 1 that 871 (50.1%) of these 1737 drivers are head injured, 242 drivers (13.9%) are thorax injured, and 290 drivers (16.7%) are lower extremity injured. Very few neck injured survivals are recorded in Taiwan's data and there are not enough to build up the C_{ij} equation of the neck. Among the survived drivers in the frontal crash, most of them are AIS < 4 injuries.

Table 1.
Number of survived passenger car driver by
principle injured body region and AIS score in
frontal crash

body region	AIS score					Total	
	1	2	3	4	5	counts	%
Head and face	512	273	31	48	7	871	50.1
Neck	1	0	1	0	0	2	0.1
Thorax	207	16	19	0	0	242	13.9
Lower extremity	95	129	65	1	0	290	16.7
Others	208	102	14	7	1	332	19.2
Total	1023	520	130	56	8	1737	100.0

The original medical cost distribution and transformed natural logarithm function data are a marked positive skewness (See Figure 1) and an approximating normal distribution (See Figure 2), respectively. This attribute of medical cost distribution is same trend in each body region. Therefore, natural logarithm of medical cost is used during the regression.

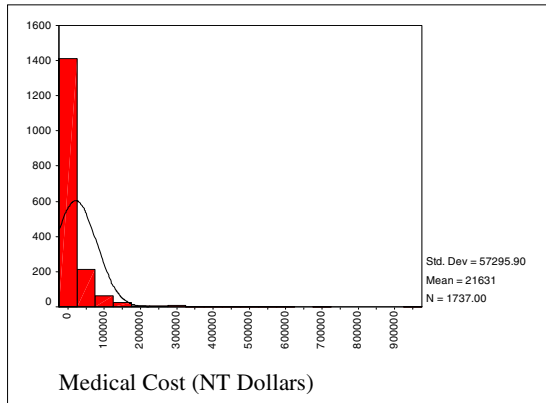


Figure 1. Original medical cost distribution of survived passenger car driver in frontal crash.
(1 US dollar = 33 NT dollar)

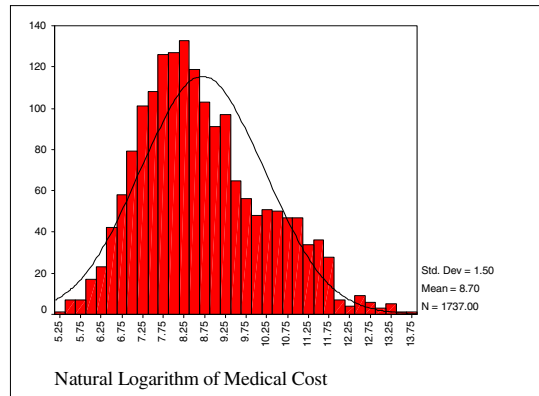


Figure 2. Natural logarithm of medical cost distribution of survived passenger car driver in frontal crash.

S_j and C_{ij} Models Development

Equations (6)~(8) and (9)~(11) are the fitted regression functions for S_j and C_{ij}, respectively. From equations (6)~(8), the probability to head, thorax, and lower extremity injured in the frontal crash are in the sequence of 0.56, 0.1, and 0.1. The fitted regression functions (9)~(11) to head, thorax, and lower extremity could explain 20%, 30%, and 50% of the variation in the associated medical cost. All the coefficients in equations (6)~(11) are statistical significant. Owing to the few records number of neck injury, the associated equations cannot be obtained in the present study.

$$S_j = \frac{e^{\alpha + \beta x}}{1 + e^{\alpha + \beta x}}$$

$x = 1$ for frontal crash, 0 for other crashes

j = Head and face

$$\alpha = 0.0058 \quad \beta = 0.2474 \quad (6).$$

j = Neck, associated data were too few to fit equation.

j = Thorax

$$\alpha = -1.8209 \quad \beta = -0.3191 \quad (7).$$

j = Lower extremity

$$\alpha = -1.6074 \quad \beta = -0.5689 \quad (8).$$

i = AIS scores, and
j = Head and face

$$C_{ij} = e^{7.541 + 0.640 \text{ AIS}} \quad (9).$$

j = Neck, associated data were too few to fit equation.

j = Thorax

$$C_{ij} = e^{6.718 + 1.129 \text{ AIS}} \quad (10).$$

j = Lower extremity

$$C_{ij} = e^{4.156 + 4.497 \text{ AIS} - 0.751 \text{ AIS}^2} \quad (11).$$

Validation of the Finite Element Simulation Model

The validation of the finite element simulation model is done by comparing the simulation output in the present study to the test results of Prasad's (1990) study. The acceleration curve used by Prasad is illustrated in Figure 3, 112ms time history and peaking at 23.7G. The same conditions are substituted into the simulation model to drive the sled. The resulted acceleration outputs are shown in table 2. In general, there is acceptable agreement in these results between the present simulation model and Prasad's study.

Table 2.
Comparison between sled simulation and Prasad's (1990) sled test.

Acceleration		Simulation	Prasad (1990)
History	Head	Figure 4.	
	Thorax	Figure 5.	
	Pelvis	Figure 6.	
Peak	Head	62G	58G
	Thorax	47G	43.5G
	Pelvis	51.5G	55G

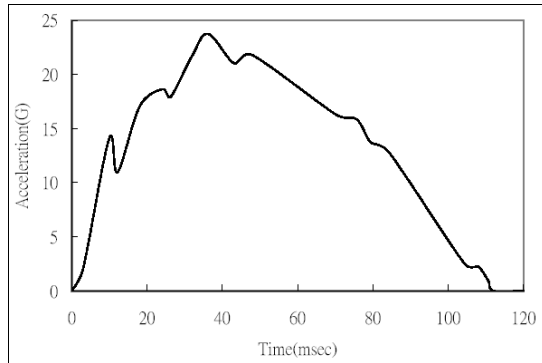


Figure 3. Frontal impact sled test pulse from Prasad (1990).

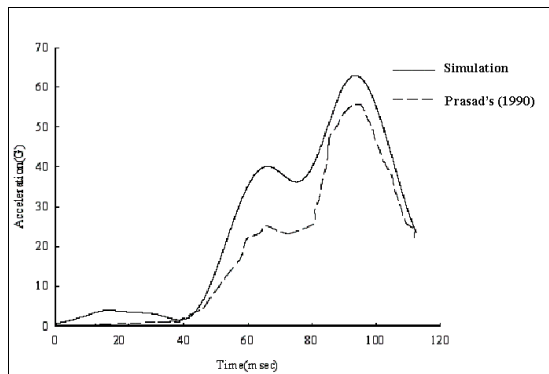


Figure 4. Head acceleration comparison between sled simulation and Prasad's (1990) sled test.

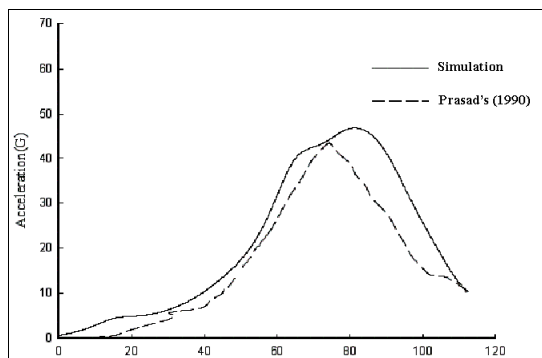


Figure 5. Thorax acceleration comparison between sled simulation and Prasad's (1990) sled test.

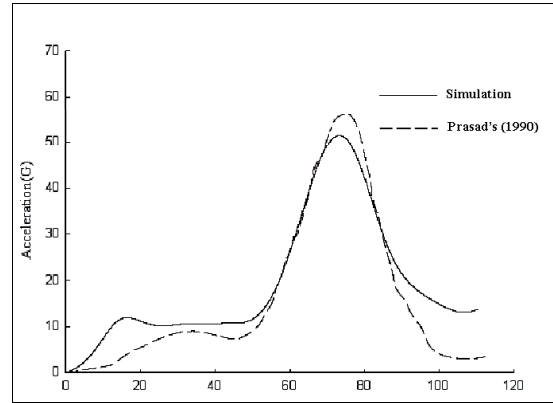


Figure 6. Pelvis acceleration comparison between sled simulation and Prasad's (1990) sled test.

Injury Criteria Calculation

By using validated finite element simulation model in the above section, a frontal crash test at 30mph (48kph) is simulated in the present study. Maximum acceleration during the frontal crash test simulation is 27.5G. Since only seatbelt and seat are included in the sled simulation model, the dynamic responses of thorax and femur cannot be simulated reasonably. The associated simulation results and the injury criteria are not stated here. It can be done when the simulation model is upgraded from sled to full vehicle model in the future. A value of $HIC_{36}=492.6$ is calculated from the peak head acceleration 53.4G. The N_{ij} to neck injury are $N_{\text{tension-flexion}} = 0.85$, $N_{\text{tension-extension}} = 0.12$, $N_{\text{compression-flexion}} = 0.06$, and $N_{\text{compression-extension}} = 0.11$. $N_{\text{tension-flexion}}$ is the highest in these four N_{ij} . According to our simulation experience in N_{ij} , $N_{\text{tension-flexion}}$ also presented the most significant variation to test speed.

Probable Medical Cost Prediction

Calculation the Probability of AIS Scores: The probabilities of $AIS \geq 3$ can be further calculated by substituting injury criteria, HIC_{36} and N_{ij} , into associated equations (2)~(3). Then, the probability of $AIS < 3$ can be obtained by 1 minus $P(AIS \geq 3)$. Because $N_{\text{tension-flexion}}$ is the highest and the most sensitive to test speed among the four N_{ij} values, it is used in the present study to represent the N_{ij} . Therefore, $N_{ij} = 0.85$ is substituted into equation (3). From the probability results shown as below, the frontal crash test at 30mph (48kph) would result $AIS \geq 3$ to head and neck injury at a probability of 0.05 and 0.11, respectively.

Head:

$$P(AIS \geq 3) = \phi\left(\frac{\ln(HIC_{36}) - \mu}{\sigma}\right) \\ = \phi\left(\frac{\ln(492.6) - 7.45231}{0.73998}\right) = 0.04525$$

$$\mu = 7.45231, \sigma = 0.73998$$

ϕ : accumulative normal distribution

$$P(AIS < 3) = 1 - P(AIS \geq 3) = 0.95475$$

Neck:

$$p(AIS \geq 3) = \frac{1}{1 + e^{3.906 - 2.185 N_{ij}}} \\ = \frac{1}{1 + e^{3.906 - 2.185 \times 0.85}} = 0.11418$$

$$p(AIS < 3) = 1 - p(AIS \geq 3) = 0.88582$$

Probable Medical Cost Prediction: The

probabilities of $AIS \geq 3$ and $AIS < 3$ calculated in the above paragraph is used to represent the $AIS = 1 \sim 5$. The $P(AIS \geq 3)$ and $P(AIS < 3)$ are the probabilities of $AIS = 1 \sim 3$ and $AIS = 1 \sim 2$, respectively. These probability values to head, associated with C_{ij} from equation (9) and S_j from equation (6), are substituted into equation (1) together to predict the medical cost of head injured to survival passenger car driver involved in the frontal impact. The predicted medical cost to head is NTD 7,687 per survival passenger car driver involved in the frontal crash. The calculation is demonstrated as below:

$j = \text{Head}$	P_{ij} (equation (2))	C_{ij} (equation (9))
$i = AIS = 1$	0.95475	x 3572
$i = AIS = 2$	0.95475	x 6775
$i = AIS = 3$	0.04525	x 12849
$i = AIS = 4$	0.04525	x 24367
$i = AIS = 5$	0.04525	x 46212

$$\sum_{i=1}^5 P_{ij} C_{ij} = 13654$$

predicted medical cost

$$= S_j \times \sum_{i=1}^5 P_{ij} C_{ij} = \frac{e^{0.0058 + 2.2474 \times 1}}{1 + e^{0.0058 + 2.2474 \times 1}} \times 13654 \\ = 0.56296 \times 13654 = 7687$$

Owing to the lack of enough neck injury records in the real crash data, the associated C_{ij} and S_j equations are not built in the present study. Therefore, the medical cost of neck, thorax and femur cannot be predicted. However, this can be done in the same way illustrated in the above when the sufficient associated data and a full vehicle model

are available.

CONCLUSIONS

In the present study, several conclusions are as follows:

1. The head, thorax, and lower extremity medical cost model built in the present study can predict the probable medical cost of survivals in the frontal crash. It is possible to choose an economic index obtained from this model to evaluate car safety.
2. By data linkage technique, crash injury information in the real world can be continuously obtained and the statistic probability model can bridge the injury assessments between real world and laboratory test data.
3. Also, the improvement of injury protection due to car design and occupant restraint can cause the change of injury severity; therefore, the affect on the medical cost can be calculated.
4. In the future, more real crash data of neck injury and the full vehicle simulation model including femur and thorax output data can be used to overcome some shortages of present model.
5. In advance, the medical cost of the fatality and long term medical burden can be considered as the associated data are available.

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